CRANFIELD UNIVERSITY

B. IGLESIAS BARES

BEST PRACTICE INDICATORS FOR NEW PRODUCT DEVELOPMENT AT UNIVERSITIES

MSc by Research
Academic Year: 2013 - 14

Supervisors: Dr Leon Williams, Dr Sue Impey
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ABSTRACT

It is public domain that the development of new products is a crucial activity for business success. Since new product development (NPD) is only conceived as a process within the industry environment, nearly all of the studies on this topic are empirically driven. The most important, and common ones, are based on surveys that look for the habits, methods, and approaches of the best performers, in order to distil NPD best practice.

Academics and practitioners generally agree that the environment at small new ventures may differ significantly from the NPD environment at large and medium sized firms. Nevertheless, the advantages attributed to the NPD best practice at large and medium sized companies may also benefit small organisations, including university projects. However, the application of this best practice within university projects needs more exploration.

This gap in the knowledge should be investigated since cooperating with external partners a key trend in NPD. Here, the scientist's expertise and the extensive resources of research universities can make them excellent partners.

This study aspires to answer the question "Is new product development at universities performed properly?". It addresses this debate by carrying out a systematic review, a content analysis, and a benchmarking performance in order to identify six indicators that are associated with higher degree of NPD success in the university environment. Subsequently, empirical data regarding the use of those practices at universities is collected using a questionnaire, then the data is analysed statistically. The results report an alignment of the NPD executed at universities with the NPD best practice indicators. The fulfillment is also compared with industry execution. Finally, the NPD best practice indicators, particularly those that universities perform noticeably better or worse than industry, are discussed.

The study provides a tool-questionnaire to organisations interested in assessing outsourced NPD processes (particularly those performed at universities). The results

obtained with this tool can be benchmarked with the industry and universities' data. This study also allows teams engaged in NPDs at universities to determine the weaknesses (i.e. methods and practices that are not usually applied) in this specific environment.

Keywords: *best, practice, indicator, performance, process, meibomian, gland, dysfunction, eyelid, massage.*

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TABLE OF CONTENTS

The following contents are included in the study:

LIST OF FIGURES

The following list of figures is used throghout the study:

LIST OF TABLES

The following list of tables is used throghout the study:

LIST OF ABBREVIATIONS

The following list of abbreviations is used throughout the study:

APQC	American Productivity and Quality Center
BIC	Business Innovation Centre
CAD	Computer Aided Design
FFE	Fuzzy Front End
MGD	Meibomian Gland Dysfunction
NDA	Non Disclosure Agreement
NPD	New Product Development
NTD	New Technology Development
NTV	New Technology Venture
PDMA	Product Development and Management Association
RTV	Room Temperature Vulcanization
R&D	Research And Development
SBU	Strategic Business Unit
UBI	University Business Incubator
USO	University Spin-Off
VoC	Voice of the Customer

1 INTRODUCTION

This section describes the study motivations, the research question, the aim, and its specific objectives. The Study audiences section also suggests who may find most useful the study, and the Study structure section how the study is organised.

1.1 Study motivations

Although concern about new product development (NPD) has increased over the last few decades, the process is still very inefficient (Edgett, 2011). Moreover, the NPD process at universities needs specific exploration. The author is not aware of any research of NPD at universities in the moment of the publication of the study. This study intends to fill that gap since there appears to be growing interest in NPD and particularly in NPD at universities:

- **Increase of new product development importance at companies.** NPD is of key importance for businesses these days: “new products launched in the last three years currently account for 27.3 percent of company sales” (Edgett, 2011).
- **Increase in the number of theses relating to product development at universities, most of them directly related to a real practical project.** On average, the number of theses related to product development at Cranfield University (UK) has tripled since 1985 to 2013 (Appendix Figure A-1). Cranfield University is used as an example of the general rise in NPD projects at universities.

1.2 Study research question, aim, and objectives

As a result of the scope and gap opportunity identification, but above all as a result of the experience of the author in developing products at a university (Appendix D.1), the research question was formulated as follows: Is new product development at universities performed properly?

The aim of this study is to evaluate universities’ performance as NPD partners. In order to achieve this, the specific objectives are:

1. To identify the industry new product development best practice indicators.
2. To collect data regarding universities' performance regarding the selected new product development best practice indicators.
3. To analyse the obtained data in order to assess how well or badly universities, as NPD partners, perform the selected new product development best practice indicators.

The lack of metrics, the long time frame and division of NPD activities among several participants, make it extremely difficult to evaluate the success of NPD process implementation. The challenge is even greater if only part of the entities involved is assessed. Consequently, this study will value universities as NPD partners by comparing their practices with well validated and benchmarked best industry practices, i.e. the NPD best practice indictors. These practices are associated with high levels of success and, although companies do not succeed just by using one practice more extensibly or better, it is accepted that the use of a number of practices effectively and simultaneously increases the probability of gain in a NPD (Barckzak & Khan, 2012; Barczak, et al., 2009). Therefore, it was decided to target NPD projects that firms with strict market objectives outsource to universities. Otherwise the comparison between university-industry would not have been meaningful, since NPD projects at universities with no industrial partner do not work under the same economic or time pressure. These two factors affect the frequency and quality of applying best NPD practice indicators.

Some authors argue that there is no general best practice in NPD, but rather this is different depending on the industry, or even project specific (above all in radical innovations) (Cooper, 2006; O'Connor & DeMartino; 2006; Davison, et al., 1999). On the other hand, many other authors argue that there exist "certain aspirational NPD best practices, regardless of context" (Barckzak & Khan, 2012), only customization of the implementation is required (Adams-Bigelow, 2005; American Productivity & Quality Center, 2003; Barczak, et al., 2009; Cooper, 1979; Cooper, 2001; Cooper, 2005; Cooper & Edgett, 2012; Cooper & Kleinschmidt, 1993; Karol & Beebe, 2007; Boike, et al., 2005; Cooper & Kleinschmidt, 2007; Cooper, et al., 2002; Griffin, 1997; Griffin, 1998).

Thus, it was decided that the best way to assess university performance was by benchmarking its result with industry.

1.3 Study audiences

The study mainly addresses three audiences:

- **Organisations interested in assessing outsourced NPD processes (particularly those performed at universities).** The study provides a tool-questionnaire to evaluate outsourced NPD. The obtained results can be benchmarked with industry and university data. These organisations can also infer from the findings of the study which parts of the NPD process are more suitable to be outsourced to a university.
- **People involved in a new product development totally or partially outsourced to a university.** This study also allows teams engaged in NPDs at universities to determine the most important activities, the strengths, and weaknesses of this specific environment.
- **Researchers** looking for general information about the best NPD practice or more particularly NPD outsourced to universities.

1.4 Study structure

Below it can be found a short description of every chapter and its contribution to the study:

Chapter 1 INTRODUCTION introduces the study problem and the value of the research. It also explains the structure of the thesis and prepares the reader to understand the flow of the text.

Chapter 2 LITERATURE REVIEW provides to the reader the necessary background knowledge to understand the study and its motivations. On the one hand the Approach to literature is explained in order to understand the motivations and importance of the study. On the other hand NPD terms and concepts are explained to fully understand the study.

Chapter 3 METHODOLOGY describes in detail the research process followed so as to obtain the FINDINGS. This involves the best practice indicators identification and the university fulfillment of those. This section also states the logic behind the selection of these particular methods. It includes Systematic review, content analysis and down-selection, Survey design, and Data analysis. The described methodology guarantees a good research rigour and relevant results.

Chapter 4 DATA COLLECTION describes in detail the execution of the methodology in order to collect the raw data. It begins with the best practice indicators identification by systematic review, content analysis and down-selection. Then, it describes how the university information was collected by means of a questionnaire and displays this data. This section provides the raw data that will be analysed statistically in the FINDINGS section.

Chapter 5 FINDINGS displays in a comprehensible way the data analysis of the results obtained through the questionnaire in the DATA COLLECTION section. It analyses statistically the university performance of the best practice indicators in comparison to other empirical studies. It focuses on those indicators that are more differently fulfilled by university and industry. This comparative analysis is the main outcome of the study and it is further extended in the DISCUSSION section.

Chapter 6 DISCUSSION intends to give a cautious interpretation of the study FINDINGS. It also compares the study outputs with other theoretical and empirical studies. It analyses every single best practice indicator of the study. At the same time, this provides validation to the study.

Chapter 7 CONCLUSION summarises the fulfillment of the study aim and objectives, i.e. the main outcomes of the study. It also provides a self assessment of the work performed and it suggests possible further research.

The **REFERENCES** section shows all the references cited in the study.

The **APPENDICES** section provides additional information that supports the research rigour and study outcomes.

2 LITERATURE REVIEW

This section provides the necessary background knowledge to understand the study and its motivations. Both the Approach to literature and the Theoretical framework information have been extracted from:

- Benchmarking studies, case studies, conference proceedings, empirical researches, internal reports, survey reports, and theoretical studies found through databases such as Scopus or Business Source Complete between February 2013 and September 2013. The search included different combinations of the terms: "new", "product", "development", "university", "best", "practice", and "collaboration".
- Specialised books from Cranfield University Norton Library (UK). The books were searched in the same period and under the same key words as the journal papers.
- The experience of the author developing a new eye care product at Cranfield University (UK) (Appendix D.1) from February 2013 until the finalization of the study (Figure 1).

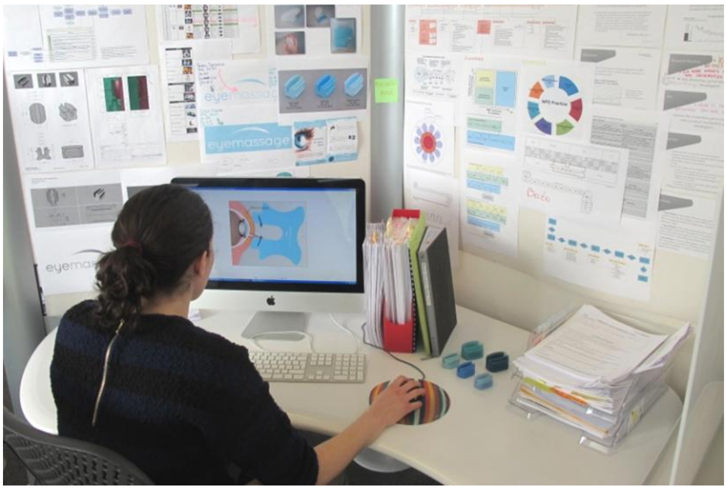

Figure 1. The author experiencing the real NPD of an eye care device at Cranfield University (UK) (Appendix D.1)

The Approach to literature focuses on the motivations while the study Theoretical framework addresses important concepts in order to understand the study.

2.1 Approach to literature

The development of new products is a crucial activity for business success. According to the American Productivity and Quality Center (APQC) and to the Product Development and Management Association (PDMA), near to one-third of companies' sales belong to products launched in the last five years. The share exceeds half of the sales if we refer only to the most successful businesses. Although concern about new product development (NPD) has increased over the last few decades, the process is still very inefficient. The percentage of successful products introduced in the market has barely changed from 1990 to 2004, less than 60% in average, and almost 75% in the best performers' case (Adams-Bigelow, 2005; American Productivity & Quality Center, 2003; Barczak, et al., 2009; Cooper, 2001).

Consequently, NPD is of key importance for industry, and it has been extensively investigated by academics. Since NPD is only conceived of as a process within the industry environment, nearly all of the studies on this topic are empirically driven. The most important, and common ones, are based on surveys that look for the habits, methods, and approaches of the best performers in order to distil NPD best practice (Adams-Bigelow, 2005; American Productivity & Quality Center, 2003; Barckzak & Khan, 2012; Barczak, et al., 2009; Cooper, 2005; Karol & Beebe, 2007). Here *best performers* are businesses "whose NPD efforts were superior on a number of performance metrics: profitability, meeting sales and profit objectives, time efficiency, and the ability to open up new windows of opportunity" (Cooper, 2005). Unfortunately, these studies usually focus on large and medium sized firms.

As stated by Muegge et al. "Researchers and practitioners generally agree that the environment at small new ventures may differ significantly from NPD at large and medium sized firms" (Muegge, et al., 2005). Nevertheless, the advantages attributed to NPD best practice indicators at large and medium sized companies may also benefit small organisations, including university projects (Muegge, et al., 2005). However, the penetration of this best practice in university projects has not been very well researched (Muegge, et al., 2005), and “little is known about integrating universities as an external partner into a company’s new product development process” (Von Zimmermann, et al., 2012) (Link, et al., 2007). For example, the APQC and the PDMA have conducted the major benchmarking investigations on NPD best practice. Although the great results of these excellent studies are undeniable, they tend to disregard the increasing propensity of companies to outsource part or the NPD process.

Cooperating with external partners is a key trend in NPD (Avarinitis, et al., 2008; Muegge, et al., 2005; Néomie, et al., 2012; Temponi & Lambert, 2001; Von Zimmermann, et al., 2012). On average, in 2003 at least one of every four projects in the portfolio was developed in joint effort with an external incubator. The literature distinguishes four main options for collaboration: Business innovation centres (BICs), university business incubators (UBIs), technology incubators, or private incubators (corporate business incubators or independent private incubators) (Barbero, et al., 2013). This study focuses on UBIs, which have increasingly attracted researcher’s attention (Avarinitis, et al., 2008; Lee, 1995; Link, et al., 2007; Muegge, et al., 2005; Von Zimmermann, et al., 2012). The scientific expertise and extensive resources of research universities can make them excellent partners for NPD. The advantages are especially relevant for technology development prior to NPD, i.e. at new technology ventures (NTVs), because these technologies are usually based on fundamental knowledge originated at universities (Markham, 2002; Muegge, et al., 2005; Von Zimmermann, et al., 2012). However, many of the conclusions of this study can be applied to the other collaboration options (BICs, technology incubators, or private incubators) as they often operate in similar conditions.

2.2 Theoretical framework

This subsection presents the concepts and classifications from the literature review that will aid to better understand the new product development process and therefore this study and its implications.

2.2.1 New Product Development process

For the purposes of this study new product development (NPD) encompasses all the activities related to the development of a new product between the time when an opportunity for a new product is seen and the time when the product is introduced to the market. In this context product refers to any product, process, or technology that is meant to be applied in a product or process that satisfies customer needs or wants. A service or an improvement in a product can also be a new product development (Karol & Beebe, 2007; Muegge, et al., 2005).

For clarity the challenges of NPD are classified by the literature under six business dimensions. Each of these key areas affects different facets of a NPD project. While the number and labelling of these dimensions is dependent on the benchmarking study, the underlying classification is very similar to all of them. Based on the most common definitions found in the literature (American Productivity & Quality Center, 2003; Barckzak & Khan, 2012) the dimensions are:

1. **Company Culture:** This area involves the organisation's internal culture and innovation approach, including management involvement and commitment, and collaboration with external partners.
2. **Strategy:** This area involves the organisation's new product strategy within its corporate strategy. It includes the definition and planning of the R&D, the technology management, and the prioritisation, selection, and resource support of development projects. It is closely related to the idea portfolio management.
3. **Project Climate:** This area involves the way projects are organised to maximize success and promote positive new product performance. It includes leading, motivating, managing, and structuring of individual and team human resources.
4. **Discovering:** This area involves the applications of methodologies and research techniques to sense, study and understand customers, users, competitors, and macro-environmental forces in the marketplace. Its purpose is to uncover new product opportunities (Cooper, 2001).

5. **Stage-Gate Process:** This area involves the actual new product development process. The most important parts and elements of the NPD process are the same from process to process, from company to company, and even from industry to industry (Karol & Beebe, 2007). Many companies approach this process systematically. Cooper's "Stage-Gate" process (Cooper, 1986) is particularly popular among NPD practitioners. It can be described as a sequence of stages (sometimes called phases) and gates (Figure 2). In every gate the project is evaluated against a prefixed criterion. If the project passes the test, it advances to the next stage; otherwise it is either cancelled or reworked (Schmidt, 2005). Although NPD involves all the steps from Research to Commercialisation, often the literature refers to the NPD Process as only the activities in between, excluding Research and Commercialisation. This preference increases when talking about the "Stage-Gate" framework, used by around 68% of U.S. product developers and embraced by firms such as Procter & Gamble, DuPont, and Nortel Networks (Cooper, 2001; Cooper, 2005).

   The first stage is called the Idea Generation stage. It is driven by the Research and it is aided by creativity tools such as brainstorming or mindmapping. The first gate, usually called First Idea Screening, sieves through the generated ideas in order to reduce the large amount of concepts to a manageable number. It is also intended to select the concepts that are aligned with the NPD strategy and to balance the idea portfolio. The Scoping stage is a desk investigation that drafts the feasibility of the project. The prescribed activities include preliminary market assessment, technical assessment, and business assessment. The Business Case is a deeper upfront research that looks to fully understand all the theoretical issues and that intends to confirm technical feasibility and benefits of the project. It includes actions such as a detailed market analysis, user needs and wants studies, competitive benchmarking, concept testing, detailed technical assessment, source of supply assessment, and a detailed financial and business analysis. The Development phase refers to the actual design and physical development of the product. The Testing and

Validation stage tests and validates the entire viability of the project, i.e. the product itself, the production process, and the customer acceptance. Finally, the activities steered to encourage the initial market penetration belong to the Launch stage.

The first half of the Stage-Gate process, called the Fuzzy Front End (FFE) or up-front work, is usually chaotic and more unpredictable than the second half (Cooper, 2001; Cooper & Kleinschmidt, 1986; Cooper, et al., 2002; Karol & Beebe, 2007; Thamhain, 2005; Von Zimmermann, et al., 2012; Watson, 2005).

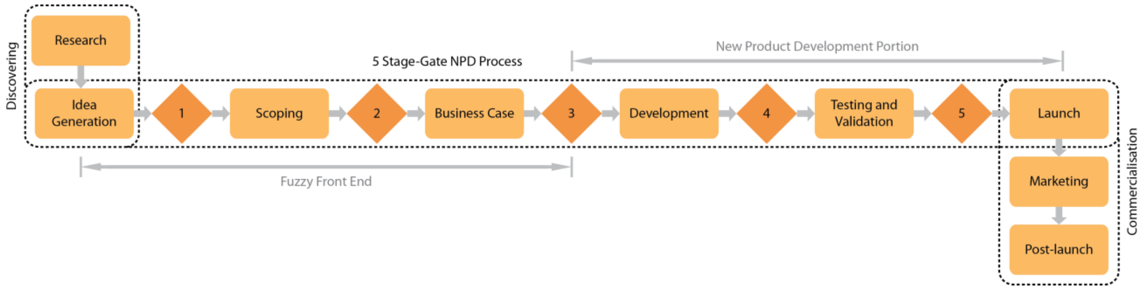

Figure 2. New Product Development process based on Cooper's Stage-Gate process

The rectangles represent stages and the diamonds gates. (After Cooper & Kleinschmidt, 1986)

It is worth pointing out that in some cases the development of one or multiple commercial projects is preceded by a new technology development (NTD). The term technology development refers to a special class of development projects where the deliverable is a new knowledge, new technology, a technical capability, or a technical platform. To better manage such projects leading companies have adopted a unique "Stage-Gate" process specially tailored to the needs of technology development projects. This process consists of three stages and four gates that feeds the front end of the typical NPD process. It usually leads into the gate before the Business Case stage (Cooper, 2006; Von Zimmermann, et al., 2012). The NTD process is very similar to the NPD process, but as there is no actual product defined, there is no market research, and some financial analyses just do not make sense (Figure 3).

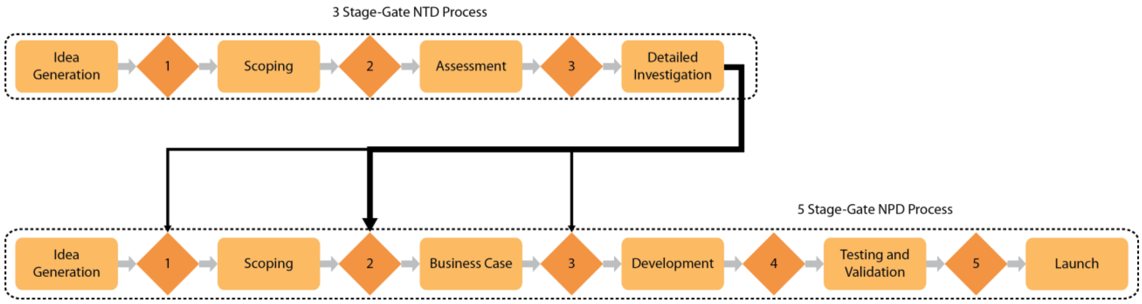

Figure 3. New Technology Development process preceding New Product Development process, based on Cooper's Stage-Gate process

(Modification from Zimmermann, et al., 2012)

6. **Commercialisation:** This area involves activities that stimulate customer adoption and market diffusion; tasks related to the marketing, launch, and post-launch management of new products.

In summary, the relationship between all the dimensions is as follows: the Company Culture is present in all the actions of the company, including those regarding NPD projects. The Strategy harmonises all the internal and external aspects of the business, including NPD strategy. The Project Climate is the way the firms approach NPD projects. Finally, the Research, Development Process, and Commercialisation gather all the activities of the actual NPD (Figure 4).

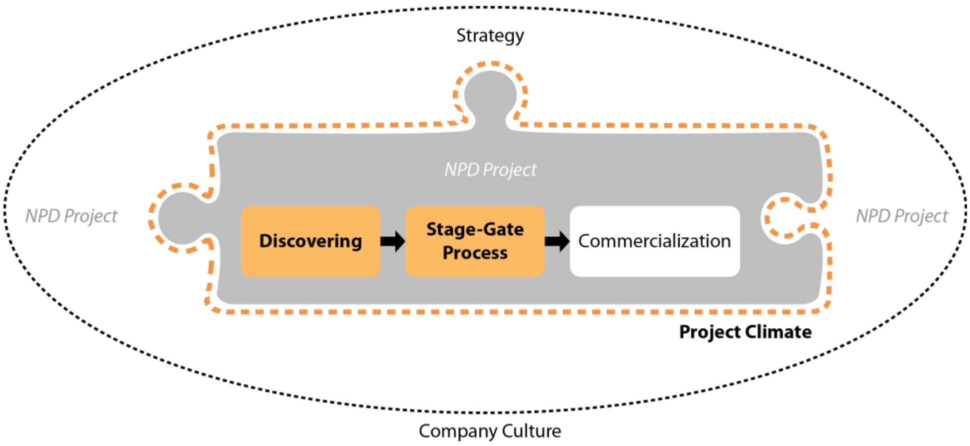

Figure 4. New Product Development dimensions graphic representation for the study

(The dimensions that affect external partners are highlighted in orange) (By Belén Iglesias Bares)

NPD practitioners rank the Strategy as the first driver for success in NPD, followed by Research, Commercialisation, Development Process, Project Climate, and Company Culture. However, the relevance of the dimensions does not vary more than 8% (Von Zimmermann, et al., 2012).

This study focuses on the Project Climate, Research and Development Process dimensions since these are the areas that are of most concern to external partners (highlighted in orange in Figure 4). The best practice indicators included in the Company Culture, the Strategy and the Commercialisation dimensions can only be applied by the firm, and not by the development partner.

2.2.2 Collaborative New Product Development

R&D requires a large amount of resources; it needs significant initial investments, permanent running costs, and time. These costs are intensified as a result of the growing complexity of technologies that demand highly specialised personnel, knowledge, and facilities. A common solution to these new challenges is looking for external partners with accumulated experience (Von Zimmermann, et al., 2012).

Engineering firms are an outsourcing option. They may attenuate costs and noticeably shorten the R&D cycles. They are easy to budget, do not need additional personnel and may reduce the complexity of the project. However, "commercial engineering firms are not suitable partners for transferring know-how since they have no interest in making their client independent from their support" (Von Zimmermann, et al., 2012). Consequently, companies tend to research technologies of strategic relevance in-house, so they can build up specific technological skills on their own. There is a danger that businesses do not gain knowledge when using engineering firms; the accumulated knowledge resides with the contractor.

In contrast, "public founded universities have the explicit duty to make the knowledge accessible both to students and to the industry" (Von Zimmermann, et al., 2012). In addition, universities can offer their laboratories and fundamental and applied research, particularly relevant in the early life cycle stage of technology; many breakthrough technologies originate from scientific findings. In fact, due to their nature, universities are more suitable for technology development than for product development. However, there are two main issues with university-industry cooperation. The first, which is not university specific, is that the current NPD processes (e.g. Cooper's "Stage-Gate" process) only consider internal R&D; external partners are not included. Secondly, universities are sometimes criticised for not being commercially oriented. The interest of the academics is "spreading their findings to gain reputation within the scientific community" (Von Zimmermann, et al., 2012). This second hurdle is particularly inconvenient as an important requirement for a successful cooperation is the conformity of goals of both partners. To overcome the differences, both organisations have to choose a cooperation form where they share a maximum of common goals. Depending on the duration, degree of integration, and financial risk, these are the prevalent forms of cooperation (Von Zimmermann, et al., 2012):

1. **Consulting:** This collaboration refers to businesses' search for advice in order to address fundamental decisions (typically at the beginning of a project) or unexpected technical challenges. Here, scientists and academics with broad and deep insight can provide good assistance. Consulting is a very short term collaboration type.
2. **Literature Research:** Technology driven companies like to conduct literature research in technological trends and potential revolutions. Hence, they can anticipate the obsolescence of their products and identify technological opportunities. Since universities commonly conduct fundamental research and have a wide overview through publications and conference meetings, they are ideal external partners. The literature research is a low cost task that can be performed in a few weeks with low or almost no interaction between the partners.
3. **Short-term Studies:** While consulting and literature research are mere collection of information, short-term studies seek an answer for a certain question. A study is usually a theoretical activity that relies on accessible data and knowledge and does not imply laboratory work. Thus, a short-term study

can be completed in about two to six months, and depending on the nature of the project, it may incur substantial costs. The interaction in this collaboration is higher, since the direction of the results may force to reformulating the question. The core objective of this cooperation fits perfectly with universities' capabilities.

4. **Long-term Research Projects:** Unlike the previous collaborations, a long-term research project not only intends to collect and prepare information, but also to generate new knowledge. It typically involves the development of a technology implemented in a product, a product itself, or a manufacturing process. A potential outcome of the project may be implemented in a prototype. In these kinds of projects universities contribute with their background knowledge and frequently with their facilities. Businesses contribute with its market experience, emphasising the commercial goals of the project. Long-term research projects may take several years, they may be costly and high risk as well. As with any kind of research activity, the desirable outcome is not guaranteed.

Experts suggest that Literature Research and Short-term Studies are the preferred cooperation forms (Von Zimmermann, Engel, Baccarella, & Voigt, 2012).

2.2.3 Collaborative New Product Development process

Since collaboration with external partners is a trend in NPD, Zimmermann proposes extending the Stage-Gate model by contract research. The author states that the extension of the established model is necessary because "the company and the university are independent organisations working in parallel for a limited period of time. They do not share a common hierarchy, therefore the hired university staff members cannot be managed the same as the internal staff members" (Von Zimmermann, et al., 2012). In his NPD collaboration models the gates are of key importance, even more important than in the original process; they are decision points and the only formal points of connection between the partners. Two models exist depending on whether the decision power falls on one or both partners, and on the amount of interaction between both parties:

1. **Non-integral Cooperation:** If the company prefers a formal nature of collaboration, it will make sure that all decisions still take place within the company. The gate keepers, as the authority, consist only of internal staff members. They alone define the deliverables and then pass them over to the university partner. The partner is treated as a "black box" and it acts purely as a contractor, handling the assignment independently. After completion, the results are handed back. Figure 5 shows the structure of the "Stage-Gate" process extended by non-integrated cooperation. It presents the outsourcing of all the stages of the process and the typical forms of cooperation at each stage. However, in a NPD not all the stages have to be outsourced and the forms of cooperation may vary.

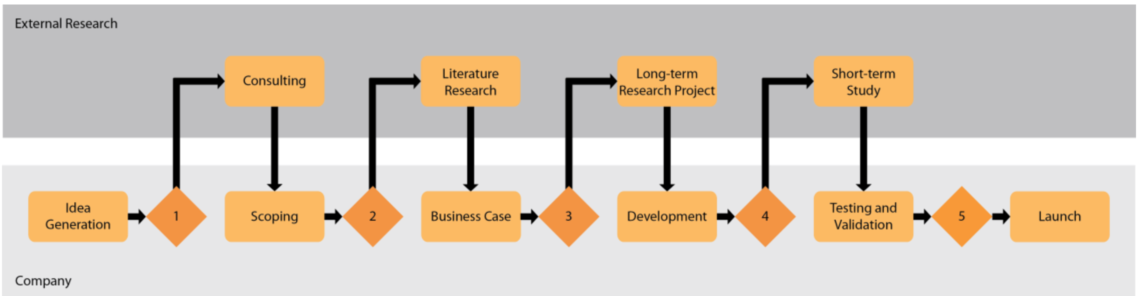

Figure 5. Stage-Gate Process extended by Non-integrated Cooperation (Modification from Zimmermann, et al., 2012)

2. **Integral Cooperation:** Unlike the non-integrated model, the tasks of both partners are merged together and work in parallel on the project. Communication is not limited to the beginning and end of an assignment, but happens on a regular basis. As a consequence, the gates now also consist of members from both the company and university. Although the company still decides about funding, the partner participates in decisions on resources and

deliverables. Figure 6 shows the structure of the "Stage-Gate" process extended by integrated cooperation. Once more, it presents collaboration with external partners in all the stages of the process and the typical forms of cooperation at each stage. If the company chooses collaboration for the whole process, the form of cooperation would be a Long-term Research Project. However, in a NPD not all the stages have to be outsourced and the forms of cooperation may vary.

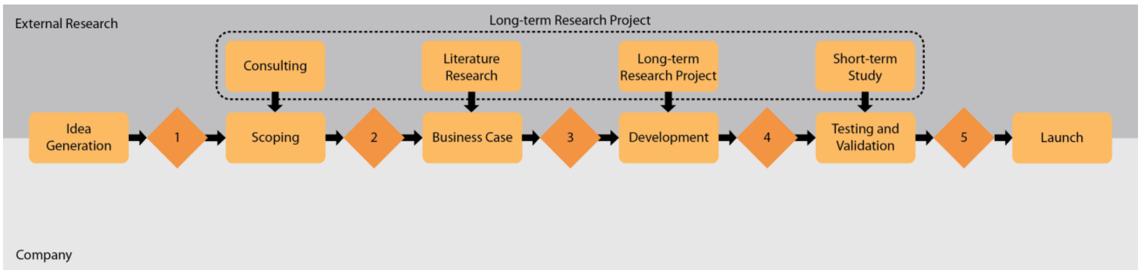

Figure 6. Stage-Gate Process extended by Integrated Cooperation (Modification from Zimmermann, et al., 2012)

Experts suggest that firms looking for preliminary development prefer integrated collaboration in the form of a six or twelve month research project. On the other hand, organisations dealing with product development tend to tilt to the non-integrated approach with short-term projects (Von Zimmermann, et al., 2012).

Zimmerman also differentiates between technology and product development. He considers the NTD that proceeds to a new product development more suitable for outsourcing, particularly when contracting research by a university. This study does not take into account such a distinction given that the structure of a product/process development and the structure of a technology development are mainly the same (Von Zimmermann, et al., 2012).

The previous Literature review allows to fully understanding the main concepts employed in this study: The research motivations and importance, the new product development process, the forms of collaboration between university and industry, and how this collaboration affects the NPD process.

3 METHODOLOGY

This section describes in detail the research process followed so as to obtain the findings. It also states the logic behind the selection of these particular methods. The described methodology guarantees a good research rigour and relevant results.

The adopted study structure is summarised and developed in Figure 7. The phases are described below and they are further explained in the next sections:

0. **Literature review and experimentation.** The broad research summarised in the literature review permits identification of the opportunity gap and the research question: Is new product development at universities properly developed? The answer to the research question guarantees at the same time the accomplishment of the research aim: To evaluate universities' performance as NPD partners. As part of the process of gaining knowledge about NPD at universities, the author has been involved in the development of a new eye care device at Cranfield University (UK) (Appendix D.1).
1. **Systematic review, content analysis, and down-selection.** The first objective is to identify NPD best practice indicators defined by industry and to identify other important variables for the research.
2. **Survey design and execution.** Once the best practice indicators are selected it is possible to assess if the NPD project is properly developed by asking if the best practice indicators have been used. Therefore, NPD projects at universities are assessed against NPD best practice indicators. The data is collected by electronic survey.
3. **Data analysis.** The data obtained by means of the survey is processed by the same statistical analysis performed by industry in order to facilitate the comparison.

Figure 7. Research methodology

(By Belén Iglesias Bares)

3.1 Systematic review, content analysis and down-selection

NPD best practice indicators are identified as a result of a systematic literature review of qualitative studies, subsequent synthesis by content analysis (including cross-case analysis), and final down-selection (Gisberta & Bonfillc, 2004; NHS Health Development Agency, 2004; Sanchez-Meca, 2010). The systematic review is the best method to select the NPD best practice indicators given that it provides access to a high number of sources and scope. Since this approach relies on many different studies, it is very reliable and the insights obtained are of a general nature: For example, the conclusions can be applied to any case independently of the industry sector or geographic location. The main disadvantage of this method is that, ideally, it should be developed by a minimum of two people; however, typically a single person performs the study's systematic review. This may result in selection bias or overlooked studies.

Find below the other methods considered and their discarding reasons:

- Observation: This method is very time consuming for the scope of this research, and it is also difficult to access to the proper mix of different industry sectors and locations.
- Workshops: The authors have limited access to specialists of NPD.
- State of art: New product development has increasingly become a key business element. However, it has not changed too much since the first studies in the 1980s.

Prior to the main systematic review, a scoping review of the literature was conducted to make sure that enough studies were available to accomplish the research.

The purpose of the systematic review is to answer the question: What are the companies' NPD best practice indicators in the Project Climate, Research, and Development Process dimensions? Where *best practice* is defined as the approaches, activities, methods and tools used in NPD and that distinguish the successful developers from the unsuccessful ones. The selected best practice indicators must be able to be formulated as binary questions that ask if a certain NPD approach, activity, method or tool is applied by the enquired entity.

It is assumed that the recommended NPD practices that appear most frequently in the reviewed literature are the best practice indicators. It is also assumed that all the studies have the same quality, so that their statements are equally valuable.

Table 1. Studies' Selection Criteria

	Inclusion/Exclusion Criteria
Location	All
Language	English
Time Frame	1990-2013 (priority to new studies)
Outcome	Studies concerned with the identification of NPD good practice either in-house business or in cooperation with an external partner. The analysed study must cover wholly at least one of the next business dimensions: Project climate, Research, or Development process.
Study Type	Books, Benchmarking Studies, Case Studies, Conference Proceedings, Empirical Researches, Internal Reports, Survey Reports, and Theoretical Studies.

The key searching words in the title, abstract, and authors are: “new”, “product”, “development”, “best practices”. Although some of the studies can be found through references in documents.

The information extracted from the literature is meant to be used in the survey as:

- Independent variables: NPD best practice indicators in industry.
- Dependent variables: Demographics and potential NPD issues (lack of resources, lack of time, lack of expertise, etc.).
- Comparison variables: Tools, techniques, and activities related to the best practice indicators. These variables allow further comparison with industry statistics.

3.2 Survey design

To find out universities' performance with regards to the identified best practice indicators, it was decided to gather the data by a questionnaire. This method allows access to a high number of cases and to obtain both quantitative and qualitative data through the same channel. On the other hand, the response bias and getting cooperation and the truth from participants is a possible source of inaccuracies. Accessing a sufficient number of appropriate participants is also a potential issue. However, the other considered methods had great drawbacks:

- Case study: Generalizing the conclusions from the case studies analysis is difficult and controversial. The selection of the case/cases has to be conducted very carefully.
- Interviews: This method is very time consuming and therefore do not allow to access to as many cases as the survey. These are better suited for qualitative data collection, while this study intends to benchmark quantitative data.
- Pure quantitative survey: Although the main objective relies on quantitative data, qualitative data would be very useful in order to complete and explain the numerical results.
- Pure qualitative data: The research intends to compare the results with industry. This data is quantitative; therefore, a pure qualitative survey is not suitable for this study.

Note that the survey design does not have to be linear; depending on the answer different questions are formulated or skipped.

3.3 Data analysis

It was decided that the best way to analyse the data was through a statistical analysis: Starting with a descriptive analysis, followed by an exploratory analysis, and finishing with an inferential analysis. For simplicity, to benefit the survey participants, the information collected is not very extensive. As a result, it is not possible to perform a predictive, causal or mechanistic statistical analysis.

The study of the data aspires to learn:

- The percentage of universities that accomplish the NPD best practice: Proportion of positive answers relating to independent variables. I.e. percentage of the best practice indicators fulfillment.
- The difference in the fulfillment degree between industry and universities: Contrast between the comparison variables from the study's survey and the industry statistics.
- When the university compliance is very different to the industry, the study suggests possible reasons, including the relation independent variables – dependent variables. I.e. find out if the demographics or a particular issue appears to be clearly related to the fulfillment or failing.

Although the relevance of the practices differ from each other, the difference itself is not very important. Therefore, and in search of simplicity, all the best practice indicators have the same statistical weight.

The analysis of universities' data and its comparison with industry's execution allow evaluating if universities are effective NPD partners. Thus, universities' statistical analysis must be the same used in other studies that evaluate industry's fulfillment of the NPD best practice (Barczak & Khan, 2012; Cooper & Edgett 2012). The comparison university-industry also intends to validate the data resulting from the survey.

The output of the Methodology sections is the certainty of that the research process guarantees the most accurate and meaningful results. The Data collection section describes in detail the execution of the Methodology.

4 DATA COLLECTION

This section describes in detail the execution of the methodology in order to collect the raw data. It begins with the best practice indicators identification by systematic review, content analysis and down-selection. Then it describes how the university information was collected by means of the questionnaire. Finally, the recorded data is displayed.

4.1 Best practice indicators

The best practice indicators identification through systematic review, content analysis and down-selection is described below:

1. The quotations regarding to NPD good practices were identified in the reviewed literature and then classified relating to the dimension and stage, if applicable. Only practices potentially developed by external partners were assessed, i.e. most of the practices developed under the Project Climate, Research, and Development Process dimensions. The practices were listed together with the source (i.e. study and author). If any particular tool or technique was associated with the best practice indicator, this was written together with the indicator. A total of 214 statements were initially subtracted from the literature in this way. After eliminating redundancies, the study ended up with more than 165 quotations in regard to the best NPD practices (Table B-3, Table B-4, and Table B-5).
2. The quotations that refer to the same practice were gathered under a single good practice statement. The relevance of the practice was evaluated adding the number of times that the related good practices was cited in the literature review. In order to avoid redundancy, if various practices came from the same study source (for instance from the PDMA 2003 or from the APQC), only one was taken into account. A total of 74 different good practice indicators were identified.
3. The indicators were ranked by relevance in Table B-6. The six most relevant quotations were selected to be included in the questionnaire. For the purpose of this research, these six practices are considered the best practice indicators in the Project Climate, Research, and Development Process dimensions. These best

practice indicators were quoted in the literature five or more times. This value represents the relevance of the practice and it is much higher than the median and the average of quotes: Median=1 and Average=2.26. The practices that were quoted four or fewer times were not selected; it is considered that four quotations are not enough to declare a practice as best. Two statements are added in order to enable the comparison with industry statistics: “Were technology tools applied in order to aid the development process?” and “Was the collaboration with the partner organisation enhanced with any formal mechanisms?”. In total eight quotations were included in the questionnaire. These good practices indicators gather almost 30% of the “relevance” of all the statements. The number of best practice indicators selected is also limited by the fact that they are meant to be included in a survey, and developing an excessively long questionnaire is not likely to result in a high number of responses.

The systematic review search was conducted between the 5th of August and the 4th October of 2013. The studies’ selection criteria are summarised in Table 1. The systematic review involved the content analysis of a total of 34 references from at least 12 different sources. The sources of information are detailed in Table B-1.

It is worth highlighting that even when the idea portfolio management is cited very often in the literature review and it appears to be a key best practice indicator, it is not included in the survey. This is due to the idea portfolio management mostly being performed by businesses in relation to their NPD strategy, and not by the development partner.

Note that this study does not intend to build an absolute ranking of the good NPD practices; it only intends to identify the most relevant practices to assess the practitioners’ execution. The list of best practice indicators shown in Table B-6 is a relative ranking.

The previous systematic review, content analysis, and down-selection make it possible to select the NPD best practice that can be performed at universities. This set of best practice indicators is the basis of the survey to assess universities' performance. The survey execution is explained in detail in the next section.

4.2 Survey execution

The best practice indicators are included in a non-linear survey in order to assess the university performance. The survey content is presented in Table 2. The graphic structure can also be found in the Figure B-1, and a complete reproduction of the same in Figure B-2.

Table 2. Survey questions.

Dimension	Statement	Question	Further questions
Demographics	N/A	Demographics – 1: Indicate the county/province/state where the university where you developed the project is located:	N/A
	N/A	Demographics – 2: Indicate the industry/sector of the partner organisation:	N/A
	N/A	Demographics – 3: Indicate the number of employees of the partner organisation:	N/A
Research	Marketplace research (market size, segmentation, competition, etc.)	Research – 1: Was marketplace research performed?	If NOT: Why Research – 1: What was the main reason for not performing a marketplace research?
	Customer/user needs obtained	Research – 2: Were customer/user needs obtained?	If NOT: Why Research – 2: What was the main reason for not obtaining the customer/user needs?

			If YES: Tool Research – 2: What tools/techniques were applied for obtaining the customer/user needs?
Development Process	A clear well defined NPD process exists (formal process is in place)	D. Process – 1: Did a clear and well defined development process exist?	If NOT: Why D. Process - 1: What was the main reason for not existing a well defined development process?
	Technology tools aid the NPD process	D. Process – 2: Were technology tools applied in order to aid the development process? *Validation question	If NOT: Why D. Process - 2: What was the main reason for not applying technology tools to aid the development process?
			If YES: Tool D. Process – 2: What technology tools were applied in order to aid the development process?
	The collaboration between NPD (external) partners is enhanced	D. Process – 3: Was the collaboration with the partner organisation enhanced with any formal mechanisms? *Validation question	If NOT: Why D. Process - 3: What was the main reason for not enhancing the collaboration with the partner organisation with any formal mechanism?
			If YES: Tool D. Process – 3: What mechanisms were applied in order to enhance the collaboration with the partner organisation?
	Tools and techniques for defining, designing, developing, and testing the product are applied	D. Process – 4: Were tools and techniques for defining, designing, developing, and testing the product/ process/ technology applied?	If NOT: Why D. Process - 4: What was the main reason for not applying any tool or technique for defining, designing, developing, and testing the product/process/technology?
			If YES: Tool D. Process – 4: What tools or techniques for defining, designing, developing, and testing the product/process/technology were applied?

Project Climate	Each project has a cross-functional team	P. Climate – 1: Was the project preformed by a cross-functional team?	If NOT: Why P. Climate – 1: What was the main reason for not performing the project by a cross-functional team?
	Each project has a clearly identifiable project leader	P. Climate – 2: Did the project have a clearly identifiable team leader?	If NOT: Why P. Climate – 2: What was the main reason for not having a identifiable project team leader?

There is not a time frame criteria for the studied projects since it was considered that the NPD best practice has not changed noticeably in the last decade, which is approximately the time that NPD has been implemented.

The questionnaire passed an ethical approval; there was neither deception nor incentives used. Anonymity was ensured in order to prevent the respondents from reporting better performance than the real due to fear to be reprehended.

The survey was directly distributed by email among potentially relevant subjects, and it was also posted in specialized forums and networks. The distribution is detailed in Appendix B.6. The contacted people in turn were asked to share the survey again with other potential subjects. This, added to the fact that the survey was totally anonymous, makes it impossible to totally define the subjects of study further from their answers to the demographic questions. The survey responses were collected between 10/10/2013 and 20/02/2014. It is worth reporting that more than 311 people were directly contacted by email and 50 questionnaires were completed, meaning that the participation was less than 16%.

The data collected by the questionnaire is summarised in Table 3:

Table 3. Survey results

(Sample size: 50 projects)

Question	University's positive answers (absolute frequency)
Demographics – 1: Indicate the county/province/state where the university where you developed the project is located:	N/A
France	3
India	1
Kuwait	1
Saudi Arabia	1
Spain	7
UK	33
Mexico	1
USA	3
Demographics – 2: Indicate the industry/sector of the partner organisation:	N/A
Consumer goods	9
Healthcare products, supplies, equipment	5
Industrial, equipment, mechanical	18
Chemical, including polymers	1
Telecommunications equipment	2
Electronics/computers	5
Software	3
Other business-to-business	2
Services	2
Other	3
Demographics – 3: Indicate the number of employees of the partner organisation:	N/A
1 to 10 employees (micro-entity)	12
11 to 50 employees (small company)	2
51 to 250 employees (medium company)	8
250 or more employees (big company)	28

Research – 1: Was marketplace research performed?	29
Why Research – 1: What was the main reason for not performing a marketplace research?	N/A
It was out of our scope	11
Omission (it was not relevant for this project)	6
Lack of expertise (we did not know how to perform it)	1
Lack of resources (budget, facilities, personnel...)	0
Lack of time	0
Lack of managerial support	1
I do not know	2
Research – 2: Were customer/user needs obtained?	37
Why Research – 2: What was the main reason for not obtaining the customer/user needs?	N/A
It was out of our scope	5
Omission (it was not relevant for this project)	3
Lack of expertise (we did not know how to perform it)	2
Lack of resources (budget, facilities, personnel...)	1
Lack of time	1
Lack of managerial support	1
I do not know	0
Tool Research – 2: What tools/techniques were applied for obtaining the customer/user needs?	N/A
Beta testing (tests of working models by users)	11
Customer site visits (observe and interview at their workplace)	23
Voice of the customer or VoC (1-on-1 in-depth interviews for needs)	23
Alpha testing (early testing with users)	5
Focus groups (interview as a group for needs)	10
Concept tests (customer evaluation of concept statements)	12
Lead users (analysis and/or inclusion)	7
Test markets	4
Gamma testing (testing with the ideal product)	0
Ethnography (observe customers and their environment for needs)	11

Concept engineering (formal method for concept development)	11
Trade-off analysis (conjoint, discrete choice modeling)	5
Pretests markets (including STM, information acceleration)	1
Creativity sessions (professionally moderated)	8
Web-based versions of above tools	0
Other	5
I do not know	0
D. Process – 1: Did a clear and well defined development process exist?	36
Why D. Process - 1: What was the main reason for not existing a well defined development process?	N/A
It was out of our scope	1
Omission (it was not relevant for this project)	2
Lack of expertise (we did not know how to perform it)	7
Lack of resources (budget, facilities, personnel...)	1
Lack of time	1
Lack of managerial support	1
I do not know	1
D. Process – 2: Were technology tools applied in order to aid the development process?	45
Why D. Process - 2: What was the main reason for not applying technology tools to aid the development process?	N/A
It was out of our scope	1
Omission (it was not relevant for this project)	3
Lack of expertise (we did not know how to perform it)	0
Lack of resources (budget, facilities, personnel...)	0
Lack of time	1
Lack of managerial support	0
I do not know	0
Tool D. Process – 2: What technology tools were applied in order to aid the development process?	N/A
Project management systems	26
Computer-aided design/engineering (CAD/CAE)	31

Document management systems	13
Rapid prototyping systems	21
Performance modeling and simulation systems	16
Product data management systems	4
Resource management systems	3
Configuration management systems	2
Knowledge management systems	9
Customer needs/requirements analysis software	3
Product portfolio management software	2
Remote collaborative design systems	3
Web-based sourcing management software	1
Virtual reality/virtual design/CAVE technology	3
Other	4
I do not know	0
D. Process – 3: Was the collaboration with the partner organisation enhanced with any formal mechanisms?	24
Why D. Process - 3: What was the main reason for not enhancing the collaboration with the partner organisation with any formal mechanism?	N/A
It was out of our scope	9
Omission (it was not relevant for this project)	8
Lack of expertise (we did not know how to perform it)	0
Lack of resources (budget, facilities, personnel...)	1
Lack of time	2
Lack of managerial support	3
I do not know	3
Tool D. Process – 3: What mechanisms were applied in order to enhance the collaboration with the partner organisation?	N/A
Integrated portfolio planning	3
Interlocking concurrent development processes	4
IT tools (shared websites and groupware)	11
Team building and training	12
Per review for performance appraisals	7

Reward	1
Performance structures	2
Subcontract licensing agreements	2
Technology licensing agreements	3
Other	2
I do not know	0
D. Process – 4: Were tools and techniques for defining, designing, developing, and testing the product/ process/ technology applied?	21
Why D. Process - 4: What was the main reason for not applying any tool or technique for defining, designing, developing, and testing the product/process/technology?	N/A
It was out of our scope	9
Omission (it was not relevant for this project)	9
Lack of expertise (we did not know how to perform it)	1
Lack of resources (budget, facilities, personnel...)	3
Lack of time	4
Lack of managerial support	1
I do not know	2
Tool D. Process – 4: What tools or techniques for defining, designing, developing, and testing the product/process/technology were applied?	N/A
Concurrent/simultaneous engineering (CE)	5
Design for manufacturing, assembly, testing: design for X (DFX)	7
Failure mode & effect analysis (FMEA)	4
Quality function deployment (QFD)	7
Value analysis/value engineering (VA/VE)	4
Six sigma analysis	3
Other	10
I do not know	2
P. Climate – 1: Was the project preformed by a cross-functional team?	32
Why P. Climate – 1: What was the main reason for not performing the project by a cross-functional team?	N/A
It was out of our scope	3

Omission (it was not relevant for this project)	6
Lack of expertise (we did not know how to perform it)	1
Lack of resources (budget, facilities, personnel...)	8
Lack of time	0
Lack of managerial support	0
I do not know	0
P. Climate – 2: Did the project have a clearly identifiable team leader?	38
Why P. Climate – 1: What was the main reason for not having a identifiable project team leader?	N/A
It was out of our scope	1
Omission (it was not relevant for this project)	7
Lack of expertise (we did not know how to perform it)	2
Lack of resources (budget, facilities, personnel...)	0
Lack of time	0
Lack of managerial support	1
I do not know	1

The survey makes it possible to gather data from the university realization regarding to the NPD best practice indicators. The analysis of this information enables assessing universities' performance on NPD projects. This statistical analysis of the data is described in the next section: Findings.

5 FINDINGS

This section displays in a comprehensible way the statistical data analysis of the results obtained through the questionnaire (Figure B-2) and summarized in Table 3. An initial assessment of the findings is also included together with the information.

The brief description of the demographics shown in Figure 8, Figure 9 and Figure 10 manifests that: Most of the respondents performed the project in the UK. The “Industrial, equipment, mechanical” and “Consumer goods” sectors cover more than half of the surveyed population. And more than 50% of the projects were in collaboration with big companies. As a result this study is more relevant for those projects with the just mentioned characteristics. This does not mean that the research conclusions cannot apply to projects included in the minority groups.

The results of the industry/sector of the partner organisation indicate that the set of projects is quite representative since it roughly matches the demographic distribution of other broader studies (Barczak & Khan, 2012). The average deviation from Barczak’s work does not exceed 7% and the maximum deviation is 17.5% in the “Chemical, including polymers industry”.

There is not an obvious effect of the demographic factors (i.e. university location, industry/sector of the partner organisation or partner organisation size) on the accomplishment of the NPD best practice.

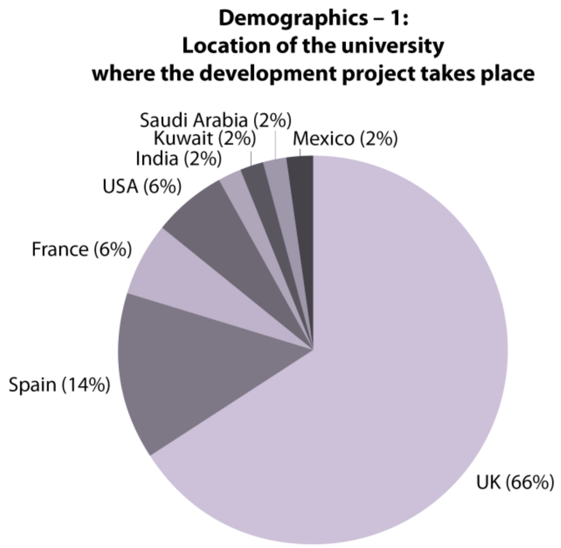

Figure 8. Location of the university project takes place

(Sample size: 50 projects)

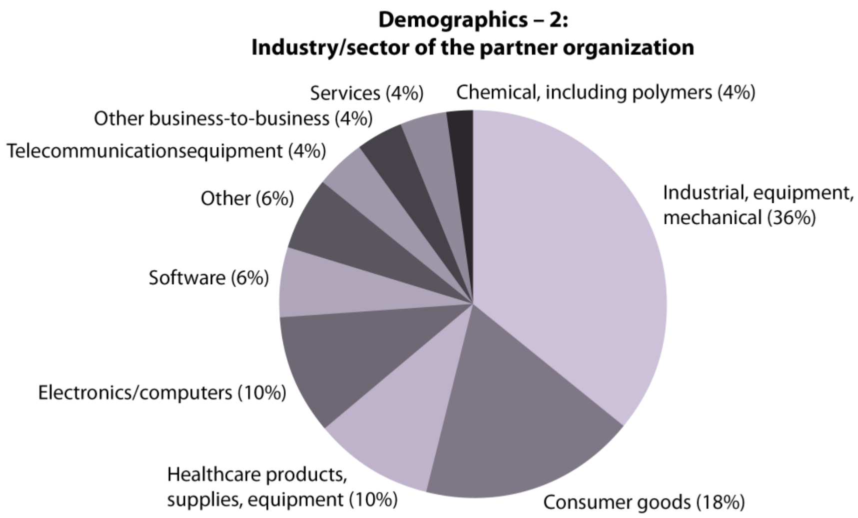

Figure 9. Industry/sector of the partner organisation

(Sample size: 50 projects)

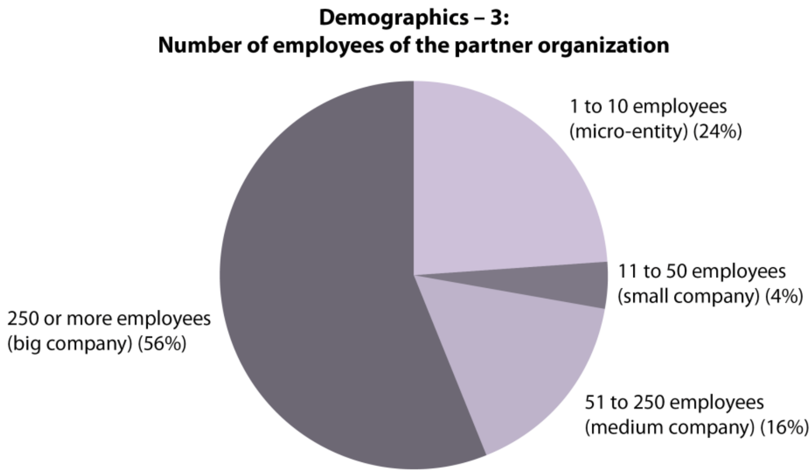

Figure 10. Number of employees of the partner organisation

(Sample size: 50 projects)

Figure 11 reveals universities' compliance with the identified best practice indicators (positive answers) compared to the industries' accomplishment obtained from the literature (Adams-Bigelow, 2005; Barczak, et al., 2009). Most of industry respondents were practitioner members of the PDMA. This bias in the industry's survey sample probably resulted in a better industry performance than the real standard (Barczak, et al., 2009).

On average, universities comply with all the best practice indicators (excluding the practices selected for validation) at 64.3%, while the industry performs at 75%. Bearing in mind that the industry's values belong to a population with tendency to perform better than the habitual, the general universities' execution is remarkable.

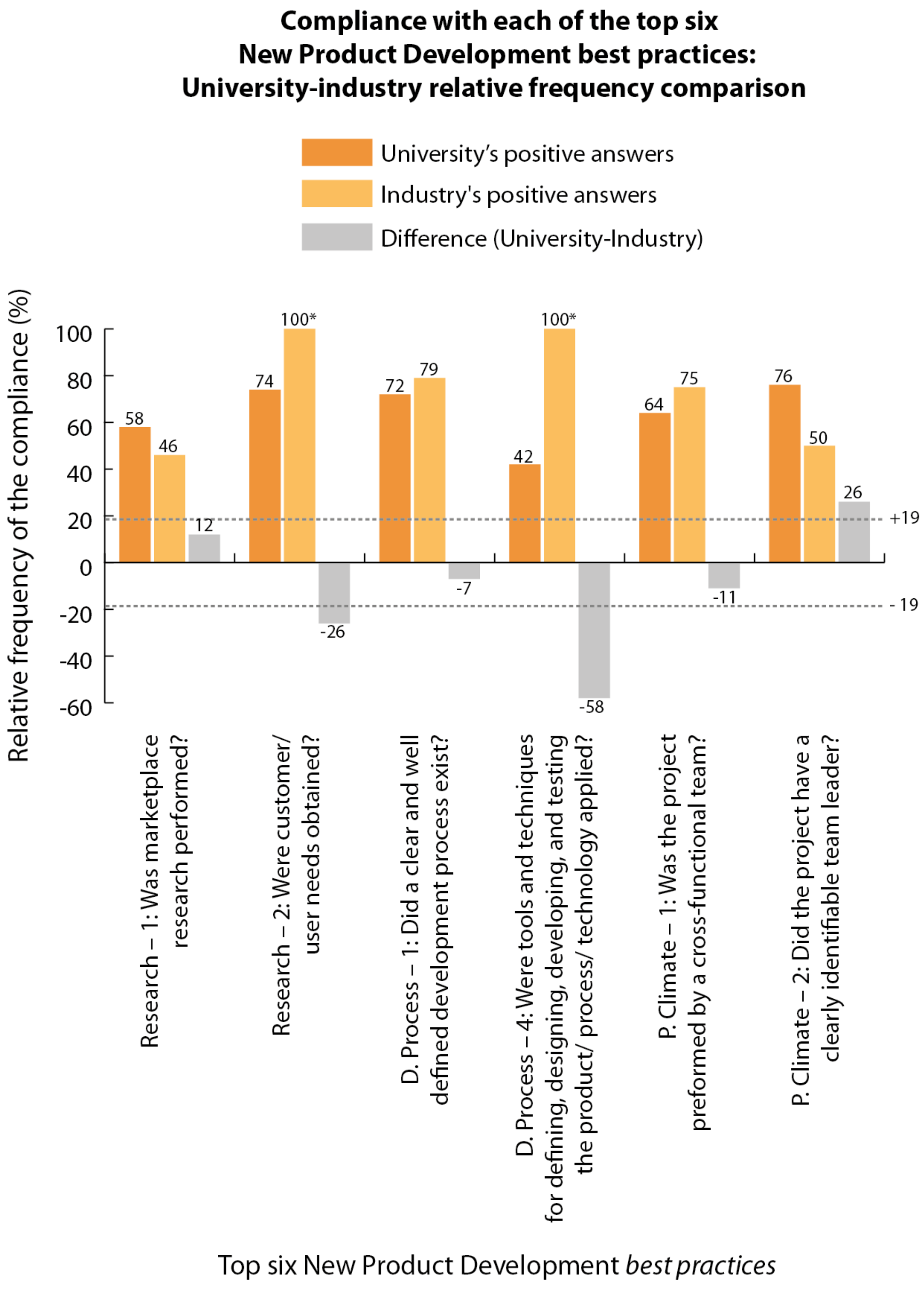

Figure 11. Compliance with each of the top six New Product Development best practice inidcators: university-industry relative frequency comparison.

Universities data: Average frequency=64.3%, Frequency median= 68.0%. Industries data (Barczak & Khan, 2012): Average frequency=75%, Frequency median=77%. Absolute value of the Difference (university-industry)'s data: Average frequency=23.3%, Frequency median=19.0%. (Universities' sample size: 50 projects)

**Industries' data of questions Research-2 and Process-4 had to be estimated*

The reasons for not following the NPD best practice indicators are distributed as shown in Figure 12. Surprisingly, most often the explanation for not following the best practice is “Omission (it was not relevant for this project)” (49%). This option was only added in case the people involved in the project considered that the practice was not relevant. However, this is not a valid reason, this study demonstrates through the systematic literature review, content analysis and down-selection that the six NPD best practice indicators included in the questionnaire are relevant for a proper NPD at industry, and therefore they should not be overlooked by universities. “Lack of expertise” (16%) is the second most popular answer. This make sense since usually students and academics do not have the necessary practical experience to apply the NPD tools, and they have less organisational learning to draw on (Muegge, et al., 2005).

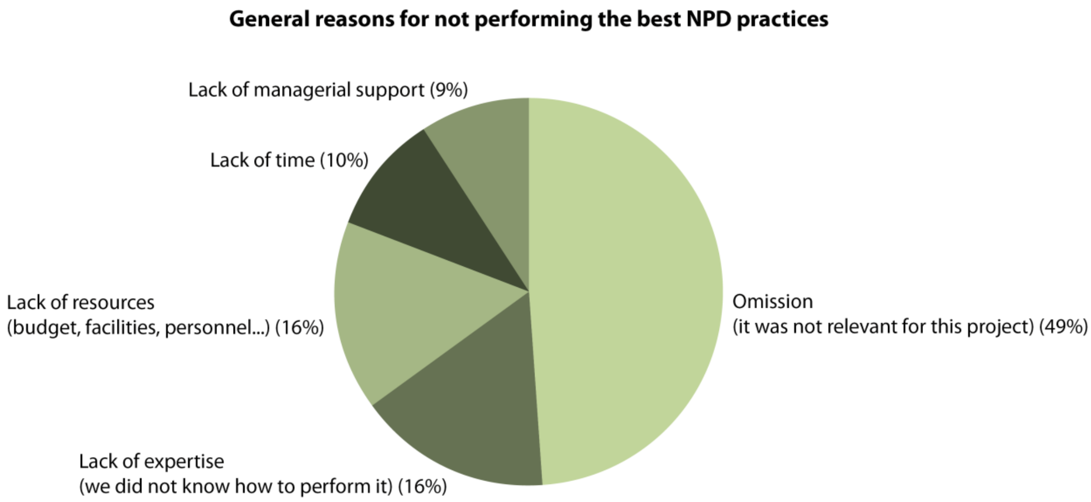

Figure 12. Relative frequency of the different reasons for not complying with the top six NPD best practice indicators

(Reasons “It was out of scope” and “I do not know” are not taken into account)

(Sample size: 89 NPD best practices not performed)

Since the study does not intend to discover the general reasons for not fulfilling the best practice, but the reasons why universities performs better or worse in comparison with industry, the research only analyses in-depth the cases in which the absolute value of the difference (university-industry) is bigger than the median: 19.0% (Figure 11). Therefore the questions analysed in-depth are:

- **Research – 2:** Were customer/user needs obtained?
- **Development Process – 4:** Were tools and techniques for defining, designing, developing, and testing the product/process/technology applied?
- **Project Climate – 2:** Did the project have a clearly identifiable team leader?

5.1 Were customer/user needs obtained?

Universities perform customer research 26% less than industry (Figure 11).

As it can be noted in Figure 13, in most of the cases the reason for not obtaining the customer/user needs was the option "It was out of scope" (38%). This may mean that even when a respondent is not aware of any customer research, there may have been one at a previous stage of the same project. However, the high percentage of respondents answering that they omitted the task (23%), supports the theory that customer/user needs are overlooked by university developers. Both reasons together cover more than the 50% of the chart. This idea is supported by the fact that universities are more suitable for NTD than for NPD (Cooper, 2006; Von Zimmermann, et al., 2012). "Lack of expertise" (15%) is in the third place in the rank, perhaps due to the lack of field experience of the university students and staff.

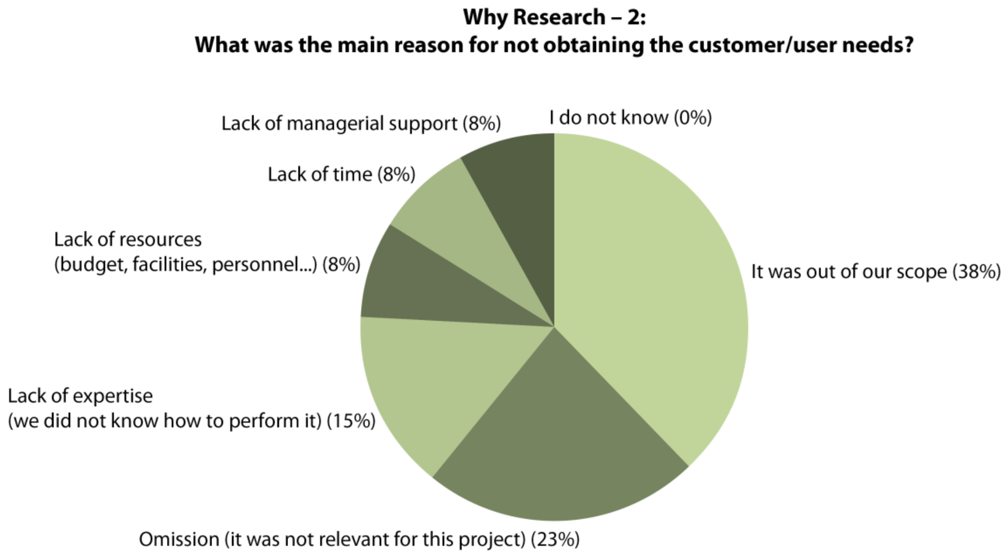

Figure 13. Relative frequency of the different reasons for not obtaining the customer/user needs (Sample size: 13 projects)

From Figure 14 it can be seen that when customer research is conducted, the university developers use almost the same tools as industry and in a similar proportion. However, the addition of all the percentages also evidences that industry generally uses 90% more tools and techniques than universities. Figure 14 also suggests that universities tend to experiment less with the use of physical prototypes for the users (i.e. alpha testing, beta testing, and gamma testing). Behind this dearth of user interaction may be the lack of market orientation associated with universities or the mentioned lack of expertise.

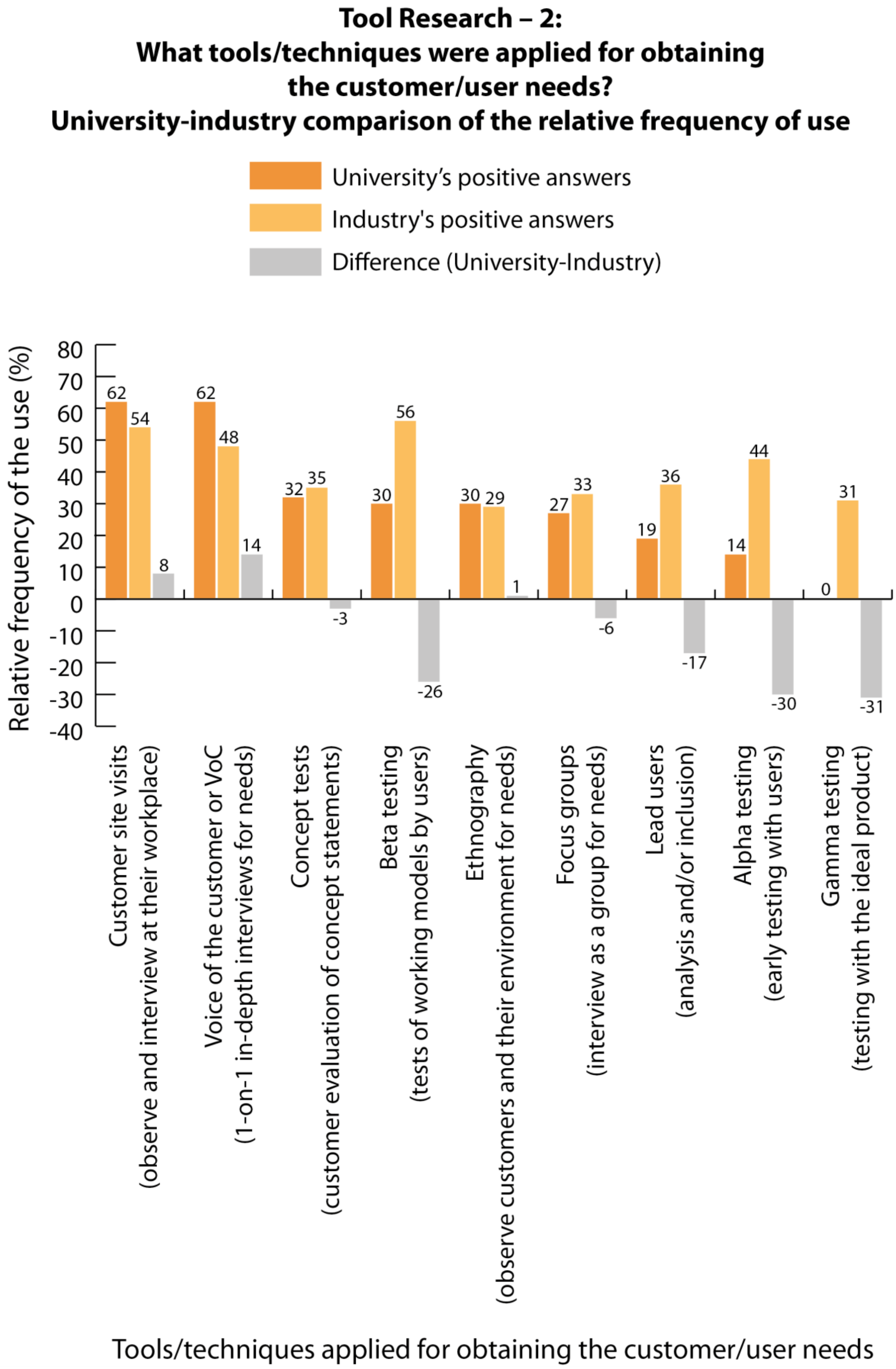

Figure 14. Tools/techniques applied for obtaining the customer/user needs: university-industry relative frequency comparison

(Industry data from (Barczak & Khan, Identifying new product development best practice, 2012)) Note that the sum of the percentages can exceed the 100% since tools can be used complementarily

(Universities' sample size: 37 projects)

5.2 Were tools and techniques for defining, designing, developing, and testing the product/process/technology applied?

Universities apply tools and techniques for defining, designing, developing, and testing the product/process/technology 58% less than industry (Figure 11).

If the justification "It was out of scope" (31%) is ignored for the reason explained in the previous point, "Omission" (31%) is again the top answer for not using tools and techniques. This study did not gather enough data to give a solid reason for this phenomenon. However, in this case the lack of resources (10%) and the lack of time (14%) occupy a big area of the chart.

Further research is needed to better explain these deficiencies.

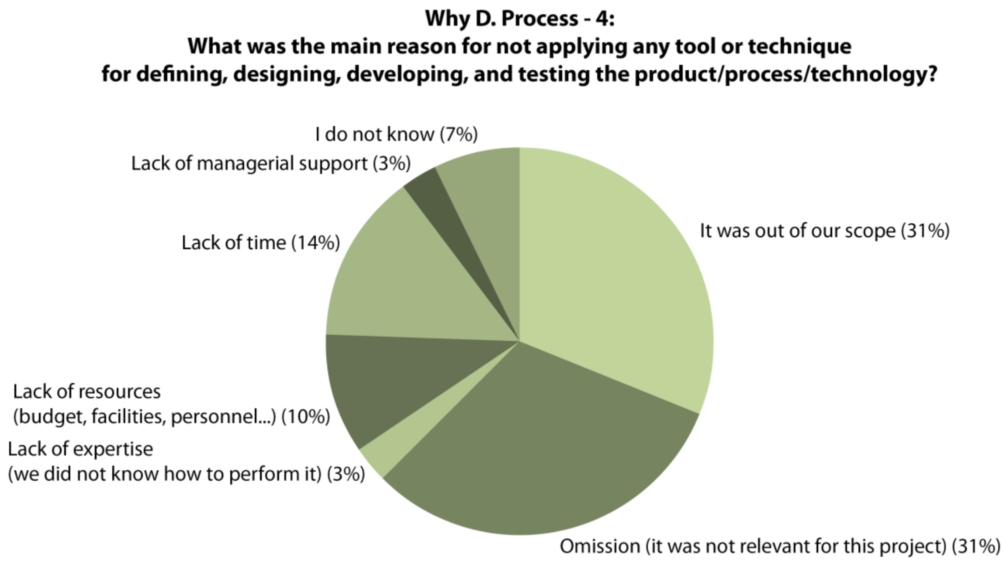

Figure 15. Relative frequency of the different reasons for not applying any tool or technique for defining, designing, developing, and testing the product/process/technology

(Sample size: 29 projects)

When using tools and techniques for defining, designing, developing, and testing the product/process/technology, universities and industry use in similar proportions the same tools or techniques. Nevertheless, industry generally applies 52% more tools and techniques than universities. The higher differences in percentages are in the use of the “Failure mode & effect analysis (FMEA)” (-19%) and in the use of the “Concurrent/simultaneous engineering (CE)” (-17%).

This divergence between universities and industry may be due to the fact that universities are commonly used for developing technologies or parts of the product, and not the whole or final part. Thus, these tools cannot be applied. Barczak et al. point out that the most used tools in industry, i.e. Design for X (particularly Design for Manufacturing) (42%), Concurrent engineering (CE) (41%), and Failure mode & effect analysis (FMEA) (38%), are mostly used in projects that intend to manufacture physical goods (Barczak, et al., 2009). This may explain in great extent why universities apply these techniques less frequently, because universities’ developments are normally focused on technologies (NTD) and not on products. Unfortunately the survey did not question whether the project was a NPD or a NTD, therefore is not possible to confirm this hypothesis.

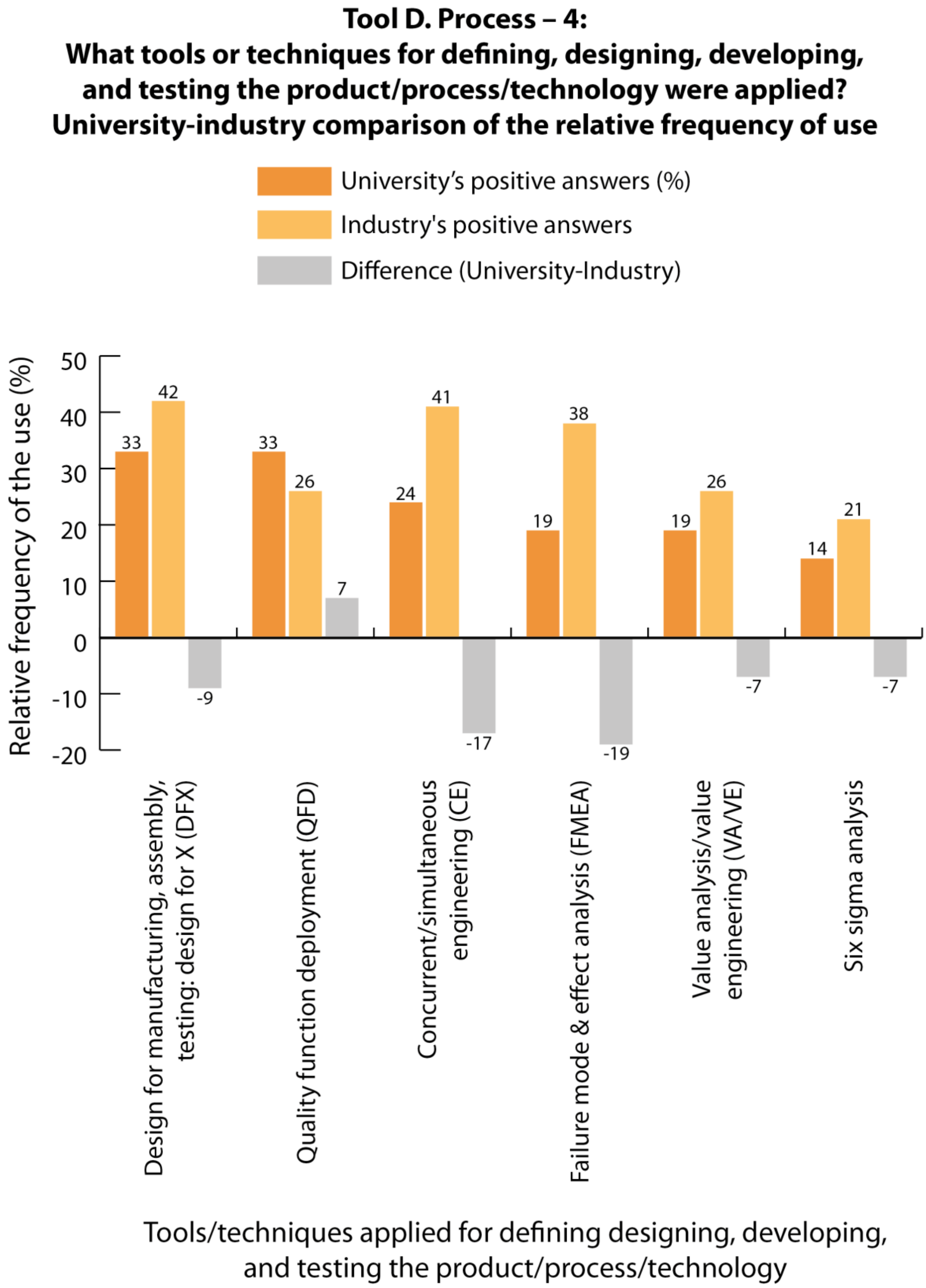

Figure 16. Tools/techniques applied for defining designing, developing, and testing the product/process/technology: university-industry relative frequency comparison (Industry data from (Barczak & Khan, Identifying new product development best practice, 2012)) Note that the sum of the percentages can exceed the 100% since tools can be used complementarily (Universities' sample size: 21 projects)

5.3 Did the project have a clearly identifiable team leader?

Universities have a clearly identifiable team leader 26% more than industry (Figure 11).

The reason behind this divergence is probably that the projects or the parts of NPD projects outsourced to universities are usually small. This possibly results in project teams composed by very few people or even an individual. The hypothesis is supported by the not very big percentage of cross-functional teams within universities (64%, against 75% in industry); it is difficult to form a cross-functional team with not many individuals. Another plausible explanation is that projects at universities have a clear hierarchy and a single liaison with the industry; Zimmermann et al. state that "Professors' [sic] play an important role in defining the scope and deliverables of each project and ensuring universities resources match the company's needs" (Von Zimmermann, 2012).

The general reason-pattern is repeated in this case. Most of the respondents state that the main justification for not having a clearly defined team leader is "Omission" (58%), then lack of expertise (17%) and lack of managerial support (17%). This last reason is the major difference between this practice and the ones analysed previously.

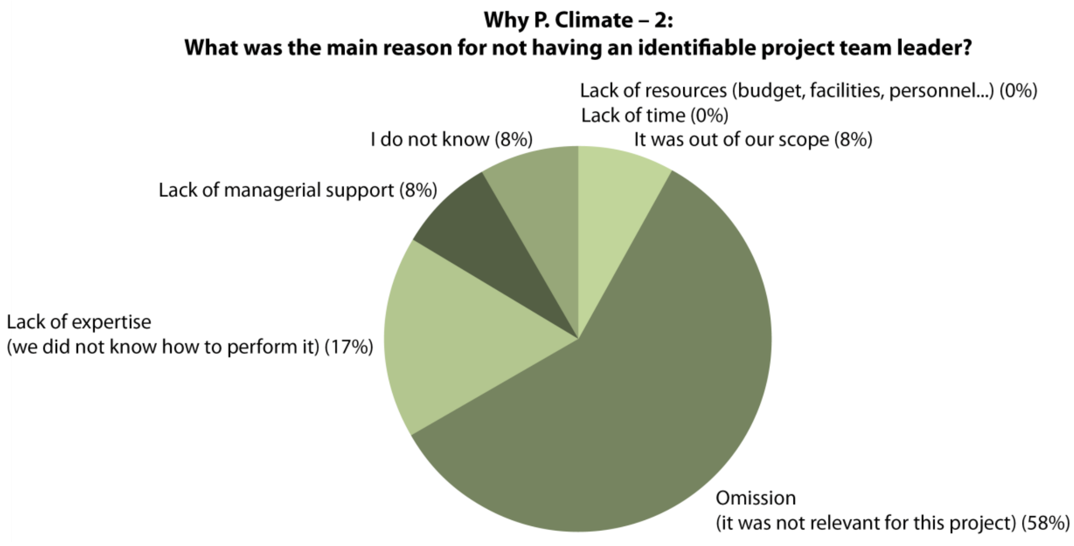

Figure 17. Relative frequency of the different reasons for not having an identifiable project leader (Sample size: 12 projects)

The Findings section provides an understandable view of the data minimally processed. It facilitates the comprehension of the results and provides an initial analysis.

In summary, the study findings demonstrate that the questionnaire sample is representative. It also shows that universities generally comply with the best practice indicators much less than industry. The findings also reveal that the most common reasons for not complying with the best practice indicators are “Omission” and “Lack of expertise”. Finally, the findings suggest that universities have a more clearly identifiable team leader than the industry. On the other hand, they do not put as much stress in customer/user needs research, and often they do not apply tools and techniques for defining, designing, developing, and testing the product, process, or technology to be developed.

The study data will be fully interpreted and compared with other theoretical and empirical studies in the next section.

6 DISCUSSION

This section intends to give a cautious interpretation of the study findings. It also compares the study outputs with other theoretical and empirical studies. At the same time, this provides validation to the study.

Notice that the results may be affected by unknown variables such us the specific nature of the development (NPD or NTD) or certain biases, for example in the respondent sample.

Is new product development at universities performed properly? Yes; as it can be inferred from Figure 11, on average universities apply best practice indicators 6 times out of 10. This is roughly 11% less than an industry sample that is “likely to be more innovation oriented than the general population of firms” (Barczak, et al., 2009). Thereby the NPD at universities share many important features with the process applied by industry practitioners with higher degree of success.

It would be too simplistic to think that just by following the six selected best practice indicators, a proper product development is guaranteed. The author, as many other benchmarking studies (Barczak & Khan, 2012), agrees with Barczak and Kenneth that “higher performance NPD companies do not succeed by just using one new product development practice more extensively or better. Rather, these companies use a number of practices more effectively, simultaneously” (Barczak, et al., 2009). Nevertheless, the fulfillment of this best practice is a very useful measurement of the development effort and execution.

Below, the study results are examined against the conclusions from other extracts found in the literature review. The discussion covers the two extra questions included in the survey for validation: “Were technology tools applied in order to aid the development process?” and “Was the collaboration with the partner organisation enhanced with any formal mechanisms?”.

6.1 Was marketplace research performed? and Were customer/user needs obtained?

Barczak et al. state that “multiple customer needs gathering market research tools are used by most of the firms” and “all of the marketing research tools used significantly more by the best” (Barczak, et al., 2009). The study results demonstrate that although universities apply a number of tools in this regard, they have less direct interaction with users. The author suggests that these deficiencies, particularly the lack of customer/user research, may be a consequence of the traditionally low market orientation of universities. Although this contrasts with the author’s practical experience (Appendix D.1). The divergence may come from the fact that the author did not work in a traditional engineering or managerial environment, but in a quite new innovation center with great focus on customer needs.

6.2 Did a clear and well defined development process exist?

Barczak et al. identified that the use a formal NPD process by firms is now the norm (Barczak, et al., 2009). The results of this study reveal that universities apply a well defined NPD process at 72% of the cases, almost with the same frequency as industry (79%). This outcome contrasts with Muegge et al. findings, who did not find formal NPD procedures in their university spin-off (USO) sample (Muegge, et al., 2005). Nevertheless, Muegge et al. warn not to generalise their finding beyond the internal validity of their sample. In addition, an USO does not behave exactly in the same manner as an NPD partner.

The particular experience of the author developing an eye care product (Appendix D.1) reveals that although there is a logical process towards developing a new product, when working in collaboration with a start-up with a single project in the pipeline, it is difficult to follow strictly the ideal NPD process. Firstly, in accordance with Timmons, information is not always available since start-ups do not have data record (Timmons, 1999). Secondly, the author experience confirms the points “The NPD resources of small NTV are typically focused exclusively on the development of a single product” (Nesheim, 2000) and “Failure of the product is more likely to result in failure of the entire firm" (Timmons, 1999). Therefore, and ironically, university projects tend to relax gate's requirements and push not very feasible projects, as they are the only ones.

6.3 Were technology tools applied in order to aid the development process?

Quoting Barczak et al. "The third major differentiator between the best and the rest is the best's seeming willingness to continually experiment with new technology tools and technologies, specially (but no means limited to) new technology-based tools" (Barczak, et al., 2009). The increasing tendency to use a wide variety of support tools for engineering design and project management is already wide-spread at universities; 90% of the projects make use of one or various engineering and management tools and techniques. Contrary to industry, universities have a clear preference for technology tools over management ones. This is probably due to the fact that universities manage projects independently, and not under one unique strategy. This is the case of the author's experience (Appendix D.1). However the study results do not concur with Muegge et al. findings, who did not observe the use of these tools and methods in their USO sample (Muegge, et al., 2005). But as mentioned before, USOs do not behave exactly as universities as developer partners, and the Muegge et al. conclusions should be solely applied to their sample.

6.4 Was the collaboration with the partner organisation enhanced with any formal mechanisms?

Although the growing complexity of technologies and the shortened product lifecycles make cooperating with external partners a key trend in NPD (Avarinitis, et al., 2008; Muegge, et al., 2005; Temponi & Lambert, 2001; Von Zimmermann, et al., 2012), such collaboration is rarely supported by enabling tools and techniques (Barczak, et al., 2009). In both cases, in industry and at universities, these techniques are used less than half of the time. According to Zimmermann et al., university-industry cooperation is far more complicated than the relation established between a company and an engineering firm. Engineering firms are usually treated as "black boxes": given certain inputs, and delivering specific outputs. There is no explanation of the process and therefore the accumulated knowledge stays on the contractor's side. On the contrary, university collaboration is usually chosen when the company wants to leverage their technology capabilities and learn as much as possible from the project. Thus, the relation must be as close as possible, and as a result, more complicated (Von Zimmermann, et al., 2012). Therefore, this study subscribes to Arvanitis' et al. quote "The interface between business and science institutions, especially universities has to be improved" (Avarinitis, et al., 2008).

On the other hand, the author's opinion based in his experience (Appendix D.1) is that if the NPD team is small (1-3 people), not many formal mechanisms are needed.

6.5 Were tools and techniques for defining, designing, developing, and testing the product/ process/ technology applied?

Universities apply tools and techniques for defining, designing, developing, and testing with less than half of the industry frequency (Barczak, et al., 2009). Muegge et al. did not observe in his group the use of these tools either (Muegge, et al., 2005). As explained in the findings, this may be due to the fact that the preferred projects outsourced to universities are NTD and not NPD.

6.6 Was the project preformed by a cross-functional team?

Although all the business roles should have an input in the NPD process (R&D, manufacturing, service, packaging, distribution, information technology, finance, human resources, marketing, etc.), only a few people are part of the core team. Muegge suggests that small NTV may be no larger than six to eight people (Muegge, et al., 2005). This is the size recommended by some consultants for a single cross-functional team (McGrath, et al., 1992). However, from the author's experience universities' NPD teams are probably smaller (Appendix D.1), and consequently, they are not cross-functional. This may explain why cross-functional teams are slightly less frequent within universities, even when they are key to success. This conclusion should be taken with caution, as it contradicts Muegge's et al. findings. The USOs from their sample were formed by highly integrated and cross-functional project teams (Muegge, et al., 2005).

6.7 Did the project have a clearly identifiable team leader?

Barczak et al. also point out that firms should improve project leadership. Nonetheless, 76% of the surveyed university developers consider that the leader position was well defined (Barczak, et al., 2009). These results concur with Muegge's et al. findings (Muegge, et al., 2005). Two possible and non exclusive reasons for the good leadership execution are: Firstly, university teams are usually small, even composed by a single member. This theory is backed by the not very high percentage of cross-functional teams at universities. Secondly, university projects are usually led by a single head; the professor (Von Zimmermann, et al., 2012). This is the case of the author's experience (Appendix D.1).

The Discussion section explains the findings and gives possible behavioral and environmental reasons for the university-industry contradictions. It does so by comparing the study results with other theoretical and empirical studies. This also validates this study. One of the major insights obtained from the discussion is that universities perform notably well the NPD, although they tend to fall in many pitfalls related to the academic environment.

7 CONCLUSION

The study aim, captured in the research question “Is new product development at universities performed properly?” is answered satisfactorily: Yes, new product development is on average properly performed at universities.

This conclusion is obtained through the completion of the study objectives:

Firstly, the systematic review, content analysis, and down-selection conclude with the identification of the six most important NPD practices indicators that can be applied to a product or process development partially or fully outsourced to a university. These are:

- “Performing a good marketplace research”
- “Obtaining customer/user needs”
- “Having a clear well defined NPD process exists (formal process is in place)”
- “Using tools and techniques for defining, designing, developing, and testing the product are applied”
- “Having a cross-functional team”
- “Having a clearly identifiable project leader”

Subsequently, empirical data from NPD university projects is gathered using a questionnaire. The obtained information intends to evaluate the compliance of these projects with the previously identified NPD best practice indicators.

Finally, the results are analysed and they reveal the alignment of the NPD performed at universities with NPD best practice indicators. The compliance is compared with industry execution resulting in the identification of the NPD best practice indicators that are much more or much less frequently developed at universities. These three of the six best practice indicators are:

- “Obtaining customer/user needs” is performed 26% less by universities than by industry

- "Using tools and techniques for defining, designing, developing, and testing the product are applied" is performed 56% less by universities than by industry
- "Having a clearly identifiable project leader" is performed 26% more by universities than by industry

The methodology was strictly followed, although, the findings should be interpreted and generalised with caution due to the limited sample size and the possible survey response bias. In addition, the involvement of more than one person in the content analysis and a better distribution of the survey (more extensive and specific) would have improved the quality of the results. The questionnaire would also have provided better outcome if more dependent variables such as the nature of the project (NPD or NTD), or the team size have been requested to the survey respondent. It would have been very helpful to have made a pilot study in order to identify these variables and potential university specific best practices. Similarly to the activities in the Fuzzy Front End of a development process, this would have avoided pitfalls.

This study highlights what the NPD best practice indicators that universities perform notably better or worse than industry are. However, further research may be required since it does not explain in detail the reasons. A qualitative study on the featured areas would explain better the reasons behind the performance difference and it would help to identify possible improvements. Another interesting area for further study could be a comparison of the market success rate between products developed at universities against other establishments. Finally, since universities appear to be demonstrably good new technology developers, a deeper insight in this field would be of the utmost interest.

Any organisation interested in assessing or self-assessing NPD processes (particularly those done at universities or simply outsourced to other organisations) will find very useful the tool-questionnaire in Table 2 or Figure B-2. Their results can be benchmarked with the industry or universities' results shown in Figure 11. This study also allows teams engaged in NPDs at universities to determine the weaknesses (i.e. methods and practices that are not usually applied) of this specific environment.

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APPENDICES

Appendix A Introduction

A.1 Interest increase on product development at Cranfield University

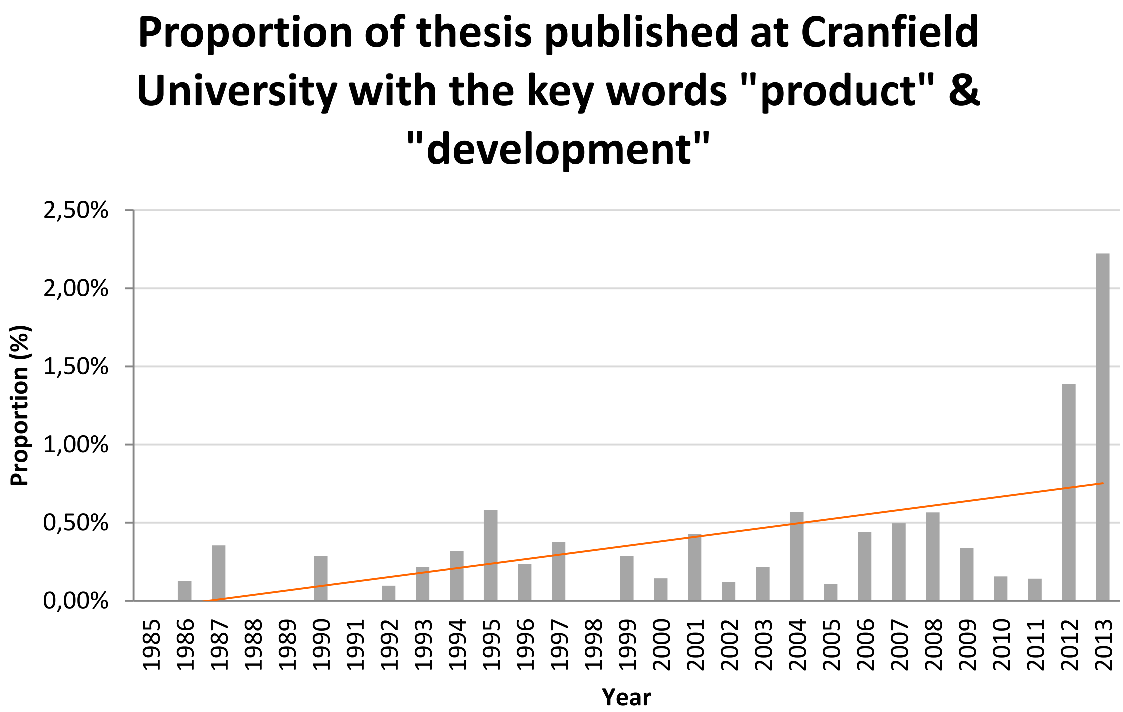
Table A-1 displays the total quantity of thesis published in the Norton Library catalogue (Cranfield University) from 1985 to 2013, and number of those theses that include the key words “product” and “development”. The word “new” was not included because it is not so commonly applied to product developments. The data from Table A-1 is graphically exposed in Figure A-1.

Table A-1. Proportion of thesis with the key words "product" & "development" published at Cranfield University between 1985 and 2013

Year	No. of thesis	No. of thesis with key words “product” & “development”	Percentage: 100*(Thesis with key words “product” & “development”)/ (Thesis)
1985	680	0	0,00%
1986	803	1	0,12%
1987	846	3	0,35%
1988	786	0	0,00%
1989	698	0	0,00%
1990	695	2	0,29%
1991	830	0	0,00%
1992	1032	1	0,10%
1993	926	2	0,22%
1994	940	3	0,32%
1995	863	5	0,58%
1996	858	2	0,23%
1997	800	3	0,38%
1998	722	0	0,00%

1999	697	2	0,29%
2000	699	1	0,14%
2001	699	3	0,43%
2002	823	1	0,12%
2003	932	2	0,21%
2004	877	5	0,57%
2005	925	1	0,11%
2006	907	4	0,44%
2007	1006	5	0,50%
2008	1060	6	0,57%
2009	1189	4	0,34%
2010	1280	2	0,16%
2011	1416	2	0,14%
2012	1009	14	1,39%
2013	225	5	2,22%
TOTAL	25223	79	0,31%

Figure A-1. Proportion of thesis with the key words "product" & "development" published at Cranfield University between 1985 and 2013



Appendix B Methodology

B.1 Systematic review and content analysis sources

The systematic review involved the content analysis of 34 references from at least 12 different study sources.

Table B-1. References and sources of the systematic review and content analysis

Reference	Study Type	Location	Study source
(Adams-Bigelow, 2005)	Book chapter	Norton library	PDMA 2003
(Alam, 2005)	Book chapter	Norton library	Various
(Barczak & Khan, Identifying new product development best practice, 2012)	Journal paper	Scopus database	Own survey
(Barczak, Griffin, & Kahn, PERSPECTIVE: Trends and Drivers of Success in NPD Practices: Results of the 2003 PDMA	Journal paper	Scopus database	PDMA 2003

Best Practices Study, 2009)			
(Boike, Bonifant, & Siesfeld, Chapter 13: Analysis and segmentation for new products, 2005)	Book chapter	Norton library	Mercer Management Consulting and R&D Magazine
(Boike, et al., 2005)	Book chapter	Norton library	PDMA's Outstanding Corporate Innovator Award
(Booz-Allen, 1982)	Book	Book	Booz-Allen & Hamilton Investigation
(Conley, 2005)	Book chapter	Norton library	Various
(Cooper, Chapter 1: New Products - What separates the winners from the loser and what drives success, 2005)	Book chapter	Norton library	PDMA 2003
(Cooper, Identifying industrial new product success: Project NewProd, 1979)	Journal paper	Business Source Complete database	Project NewProd
(Cooper, Winning at new products: Accelerating the process from idea to launch (Third edition), 2001)	Book	Norton library	Early Investigations
(Cooper, Winning at new products: Accelerating the process from idea to launch (Third edition), 2001)	Book	Norton library	Various
(Cooper & Edgett, Best Practices in the Idea-to-Launch Process and Its Governance, 2012)	Journal paper	Business Source Complete database	APQC and PDI (Product Development Institute)
(Cooper & Edgett, Best Practices in the Idea-to-Launch Process and Its Governance, 2012)	Journal paper	Business Source Complete database	Various
(Cooper, Edgett, & Kleinschmidt, Optimizing the Stage-Gate Process: What Best-Practice Companies Do - I, 2002)	Journal paper	Scopus database	Various
(Cooper & Kleinschmidt, Winning	Journal paper	Business Source	Cooper-Kleinschmidt

business in product development: Critical success factors, 2007)		Complete database	Benchmarking studies
(Cooper & Kleinschmidt, Winning business in product development: Critical success factors, 2007)	Journal paper	Business Source Complete database	Project NewProd
(Griffin, Drivers of NPD Sucess: The 1997 PDMA Report, 1997)	Report	Journal paper	PDMA 1998
(Griffin, PDMA research on new product development: Updating trends and benchmarking best practices, 1998)	Journal paper	Scopus database	PDMA 1998
(Griffin, Chapter 14: Obtaining customer needs for product development, 2005)	Book chapter	Norton library	Various
(Karol & Beebe, 2007)	Book	Norton library	Various
(Khan, 2005)	Book chapter	Norton library	Various
(Larson & Gobeli, 1988)	Journal paper	Business Source Complete database	Various
(Miller, 2005)	Book chapter	Norton library	Various
(Muegge, Sharma, & Kumar, 2005)	Journal paper	Scopus database	Various
(Ottum, 2005)	Book chapter	Norton library	Various
(Schmidt, 2005)	Book chapter	Norton library	Various
(Smith, 2005)	Book chapter	Norton library	Various
(Song, Montoya-Weis, & Schmidt, 1997)	Journal paper	Business Source Complete database	Journal paper
(Thamhain, 2005)	Book chapter	Norton library	Various
(Watson, 2005)	Book chapter	Norton library	PDMA 1998
(Wilson, 1991)	Internal Report	Journal paper	Hewlett-Packard
(Zirger & Maidique, 1990)	Journal paper	Business Source Complete database	Stanford Innovation Project

B.2 Best New Product Development practices extracted from the literature review

The NPD practices obtained from the reviewed literature are classified regarding their dimension: Research, Development Process, and Project Climate. A total of 214 statements were initially identified in the literature. After eliminating redundancies, the study ended up with more than 165 quotations regarding to the best NPD practice indicatorsc.

The numbers in the following tables (Table B-3, Table B-4, and Table B-5) allude to the references displayed in Table B-2.

Table B-2. Referece key

Number	Reference
[1]	(Barczak & Khan, Identifying new product development best practice, 2012)
[2]	(Adams-Bigelow, 2005)
[3]	(Barczak, Griffin, & Kahn, PERSPECTIVE: Trends and Drivers of Success in NPD Practices: Results of the 2003 PDMA Best Practices Study, 2009)
[4]	(Karol & Beebe, 2007)
[5]	(Boike, Bonifant, & Siesfeld, Chapter 13: Analysis and segmentation for new products, 2005)
[6]	(Griffin, Chapter 14: Obtaining customer needs for product development, 2005)
[7]	(Conley, 2005)
[8]	(Alam, 2005)
[9]	(Ottum, 2005)
[10]	(Cooper, Winning at new products: Accelerating the process from idea to launch (Third edition), 2001)
[11]	(Cooper, Identifying industrial new product success: Project NewProd, 1979)
[12]	(Zirger & Maidique, 1990)
[13]	(Wilson, 1991)
[14]	(Cooper & Kleinschmidt, New Products: The Key Factors in Success, 1993)
[15]	(Griffin, Drivers of NPD Sucess: The 1997 PDMA Report, 1997)
[16]	(Cooper, Chapter 1: New Products - What separates the winners from the loser and what drives success, 2005)
[17]	(Boike, et al., 2005)
[18]	(Cooper & Kleinschmidt, Winning business in product development: Critical success factors, 2007)
[19]	(Griffin, PDMA research on new product development: Updating trends and benchmarking best practices, 1998)
[20]	(Cooper & Edgett, Best Practices in the Idea-to-Launch Process and Its Governance, 2012)

[21]	(Booz-Allen, 1982)
[22]	(Thamhain, 2005)
[23]	(Smith, 2005)
[24]	(Muegge, Sharma, & Kumar, 2005)
[25]	(Schmidt, 2005)
[26]	(Khan, 2005)
[27]	(Miller, 2005)
[28]	(Cooper, Edgett, & Kleinschmidt, Optimizing the Stage-Gate Process: What Best-Practice Companies Do - I, 2002)
[29]	(Larson & Gobeli, 1988)
[30]	(Watson, 2005)
[31]	(Song, Montoya-Weis, & Schmidt, 1997)

Table B-3. Best Research NPD practice indicators extracted from the literature review

Best Practice	Quotations	Tools/Activities	Reference	Source
Concept, product, and market testing is consistently undertaken, and results are formally evaluated	Concept testing is consistently undertaken and expected with all NPD projects		[1]	Own survey
	Product testing is consistently undertaken and expected with all NPD projects		[1]	Own survey
	Market testing is consistently undertaken and expected with all NPD projects		[1]	Own survey
	Results of testing (concept, product, market) are formally evaluated		[1]	Own survey
A strong market orientation*	Vs. Little if any market research is undertaken		[1]	Own survey
	Vs. No market studies are undertaken to understand marketplace		[1]	Own survey
	Customer/user is an integral part of the NPD process		[1]	Own survey
	Market research: Tools/Methodologies	Beta testing (tests of working models by users)	[2]	PDMA 2003

		Customer site visits (observe and interview at their workplace)		
		Voice of the customer (1-on-1 in-depth interviews for needs)		
		Alpha testing (early testing with users)		
		Focus groups (interview as a group for needs)		
		Concept tests (customer evaluation of concept statements)		
		Lead users (analysis and/or inclusion)		
		Gamma testing (testing with the ideal product)		
		Ethnography (observe customer and their environment for needs		
		Test markets		
		Concept engineering (formal method for concept development)		
		Trade-off analysis (conjoint, discrete choice modeling)		
		Pretests markets (including STM, information acceleration)		
		Creativity sessions (professionally moderated)		
		Web-based versions of above tools		
	Market research: Tools/Methodologies	Beta testing	[3]	PDMA 2003
		Customer visits		
		VoC		
		Alpha testing		
		Lead users		
		Concept test		
		Focus group		
		Concept Engineering		
		Trade-Off Analysis		
		Gamma testing		
		Ethnography		
	Meet the needs of potential customers	Customer visits, review of the findings	[4]	Various

	Attract customers by being different from competitors' products		[4]	Various
	Key market analysis practices	Understanding how products will meet defined customer needs and be differentiated	[5]	Mercer Management Consulting and R&D Magazine
		Verifying that the final product delivers on customer expectations		
		Creating a market/customer-oriented culture		
		Formulating early definitions of product development process		
		Involving customer directly in the new product development process		
		Encouraging partnerships with customers to develop new business opportunities		
		Using customer/market research effectively throughout a project		
	Basic approaches to Market Analysis for New Product Development: Qualitative and Quantitative Techniques	Industry analogies (benchmarking)	[5]	Mercer Management Consulting and R&D Magazine
		Focus groups		
		Ethnography		
		Preference survey		
		Attribute experiment		
		In-market-based research		
		Segmentation of the market		
	Techniques for obtaining user needs	Be a user	[6]	Various
		Critically Observe Users		
		Interview Users for Needs		
	Contextual research	Contextual Research	[7]	Various
	Customer research	In-depth interviews	[8]	Various
		Focus groups and brainstorming		
		Innovation retreats and summits		
		Customer inducted into a NPD team		
		Customer panels and groups		
		Observation of customers		
		Voice of the customer techniques		
	Qualitative market research	Segmentation	[9]	Various

		Perceptual Mapping Kano Method and Needs Ranking Concept testing Conjoint Analysis		
	Strong commitment and orientation to the marketplace	Market studies (user needs-and-wants studies, concept tests, field trials, and test markets), Voice of the Customer	[10]	Early investiga tions
	Strong market orientation		[11]	Project NewPro d
	Successes have a quality R&D effort, based on strong interfaces with the customer		[12]	Stanford Innovati on Project
	Understanding user needs: The product's potential user customer and product's contribution to the customer are totally understood by the project team.		[13]	Hewlett-Packard
	Competitive analysis and product superiority: The competitors' solution for customer problems are well understood, and every effort is made to create a product plan that ensures that the new product will be better than the competitors' at the time of the market launch.		[13]	Hewlett-Packard
	Product positioning: The product is positioned correctly, based on an in depth understanding of users' needs and purchase motivations, in order to provide higher value to the user than competitive products.		[13]	Hewlett-Packard
	A strong market orientation	Voice of customer built in	[14]	Project NewPro d
	Qualitative market research	Voice of the costumer: one-on-one in-depth situation-based customer	[15]	PDMA (1998)

		interviews Customer site visits: in-depth interviews conducted at the customer's place of work or residence Concept testing: potential users provide either qualitative or quantitative reactions to concepts prior to development Beta site testing: evaluation of the product prototype and precommercial product's performance in actual use conditions		Benchmarking study
	Vs. A lack of market orientation: Inadequate market analysis, a failure to understand customer needs and wants, and insufficient attention to the marketplace are consequently cited as major reasons for new product failure		[10]	Various
	Vs. A lack of product value for the customer: Moving ahead into product development with only a vague understanding of customer requirements leads to too many ill-defined products that provide little significant benefit or value for the customer.		[10]	Various
	Strong market orientation: A market driven and customer-focused new product process – is critical to success		[10]	Various
	A strong Market Orientation – Market Driven, Customer Focused	Focus group VoC	[16]	PDMA 2003
	A strong Market Orientation – Market Driven, Customer Focused. Verifying all assumptions about the winning design	Concept tests Rapid-prototype-and-test Customer trial Test marketing	[16]	PDMA 2003
	A strong Market Orientation: Market Driven, Customer Focused	Competitive product analysis (competitive benchmarking)	[16]	PDMA 2003

Technological and marketing leverage	Technological leverage		[11]	Project NewProd
	There exists marketing and technological synergy (a good fit between the project needs and company capabilities)		[12]	Stanford Innovation Project
	Leverage – where the project builds on business's technology & marketing competencies		[14]	Project NewProd
The R&D process is well planned and executed	The R&D process is well planned and executed		[12]	Stanford Innovation Project
Successes have a quality R&D effort, based on strong interfaces with manufacturing	Successes have a quality R&D effort, based on strong interfaces with manufacturing		[12]	Stanford Innovation Project

Table B-4. Best Development Process NPD practice indicators extracted from the literature review

Best Practice	Stage	Quotations	Tools/Activities	Reference	Source
A clear well defined NPD process exists	All	A clear NPD process exists (TABLE)		[1]	Own survey
		Formal approach to NPD		[3]	PDMA 2003
		A well-defined product development process		[17]	PDMA's Outstanding Corporate Innovator Award
		Logical and stepwise flow of activities: New product process		[10]	Early investigat

					ions
		A high-quality new product development process: One that demands up-front homework (both market and technical assessments), sharp and early product definition, tough go/kill decision points, and quality of execution and thoroughness, yet provides flexibility (stages and decision points can be collapsed, combined, or overlapped, as dictated by nature and risk of the project).		[18]	Cooper-Kleinschmidt Benchmarking studies
		New product processes are vital		[19]	PDMA (1998) Benchmarking study
		Clear, defined new-product development process – a game plan, playbook, or Stage-Gate system that guides new-product development projects from idea to launch		[20]	APQC and PDI (Product Development Institute)
A common NPD process cuts across company groups	All	A common NPD process cuts across company groups (TABLE)		[6]	Own survey
The company follow a multistep NPD process	All	The multistep new product process is an essential ingredient in successful new product development.		[21]	Booz-Allen & Hamilton Investigation
		Company that follows multistage new product process – a Stage-Gate process – fare much better.		[10]	Various
The NPD process is well documented	All	The NPD process is well-documented (TABLE)		[1]	Own survey
		The processes documented at an operational level: to be operational, an		[20]	APQC and PDI

		effective new product development process should be well mapped and well documented.			(Product Develop ment Institute)
The NPD process is visible to all the NPD personnel		The NPD process is visible to all the NPD personnel (TABLE)		[1]	Own survey
		The processes are visible at an operational level: to be operational, an effective new product development process should be well mapped and well documented.		[10]	APQC and PDI (Product Develop ment Institute)
	All	Communication and control:		[22]	Various
The NPD process is executed with discipline and quality		Vs. There is no discipline in using the company's NPD process (TABLE) Vs. The NPD process can be circumvented without management approval (TABLE)		[1]	Own survey
		Quality of Execution of Key Tasks	Checkpoints	[16]	PDMA 2003
			Metrics		
			Mandatory activities		
		The processes are really used . The processes incorporate compliance to ensure that the process is followed: Monitoring to see how well the process is followed is a good way to determine if the system is truly deployed.		[20]	APQC and PDI (Product Develop ment Institute)
		Vs. Poor quality of execution: The new product process is replete with deficiencies; errors of omission and errors of commission abound.		[10]	Various
		The lack of a systematic new product process with discipline: Many companies complain that their new product process is not working. Key tasks don't happen when they should or as well as they should.		[10]	Various
	All	More emphasis is needed on completeness, consistency, and quality of execution of key tasks from		[10]	Various

		beginning to end of project. New product success is controllable.			
The NPD processes enable project teams to access resources they need to succeed	All	The NPD processes enable project teams to access resources they need to succeed: Another test		[10]	APQC and PDI (Product Develop ment Institute)
Continuous improvement of the process	All	Continuous improvement: Internal learning is leveraged and the process is improved over time.		[10]	APQC and PDI (Product Develop ment Institute)
Technology tools aid the NPD process*	All	Technology tools aid the NPD process	Project management systems	[2]	PDMA 2003
			Computer-aided design/engineering (CAD/CAE)		
			Document management systems		
			Rapid prototyping systems		
			Performance modeling and simulation systems		
			Product data management systems		
			Resource management systems		
			Configuration management systems		
			Knowledge management systems		
			Customer needs/requirements analysis software		
			Product portfolio		

			management software		
			Remote collaborative design systems		
			Web-based sourcing management software		
			Virtual reality/virtual design/CAVE technology		
		Technology tools aid the NPD process	Document Management Systems	[3]	PDMA 2003
			Project Management Systems		
			Rapid prototyping		
			Product Data Management System		
			Performance Simulation Systems		
			Resources Management Systems		
			Computer-aided design/engineering (CAD/CAE)		
Speed of Execution	Process	Speed – But Not at the Expense of Quality of Execution		[16]	PDMA 2003
		Fast development	Overlapping activities	[23]	Various
			Process Control Approaches: Fuzzy gates or fewer gates		
			Project Management Tools: The project manager must have authority to take action. Project management provides effective tools for estimating and planning project schedules. Employ project management software. Establish a baseline schedule and do not alter it.		

			Team Techniques: High-performance team; single-leader discipline or team discipline.		
			Product Related Tools: Developing deep understanding of the product. Roll out features sets incrementally.		
			Staffing Techniques: Proper number of workers.		
		Fast development	Overlap and interaction of activities, including early involvement of functional stakeholders and parallelism of development tasks.	[24]	Various
The NPD process is flexible and adaptable to meet the needs, size, and risk of individual projects	All	The NPD process is flexible and adaptable to meet the needs, size, and risk of individual projects (TABLE)		[1]	Own survey
		Significantly more gates are used when developing innovative new products compared incrementally new products		[25]	Various
		A product development process unique to their market and technology environment		[17]	PDMA's Outstanding Corporate Innovator Award
		The processes are adaptable and scalable: Is the process flexible, able to adapt to the needs, size, and risk of the project? The process should be flexible and scalable, having different versions.		[20]	APQC and PDI (Product Development Institute)

An IT infrastructure with appropriate hardware, software, and technical support is available to all NPD personnel	All	An IT infrastructure with appropriate hardware, software, and technical support is available to all NPD personnel (TABLE). Vs. Not all NPD personnel have access to the same IT tools (software, hardware) (TABLE)		[1]	Own survey
The collaboration between NPD (external) partners is enhanced	All	Collaboration mechanisms are used.	Interlocking dev process Co-located Teams Shared Risk Technology licensing Top management support	[3]	PDMA 2003
		Mechanisms for collaboration with external partners	Integrated portfolio planning Interlocking concurrent development processes IT tools (shared websites and groupware) Team building and training Per review for performance appraisals Reward Performance structures Subcontract licensing agreements Technology licensing agreements	[3]	PDMA 2003
Go/No-Go criteria are clear and pre-defined for each review gate	Gates	Go/No-Go criteria are clear and pre-defined for each review gate (TABLE). Vs. Criteria for evaluating NPD projects are not defined (TABLE)		[1]	Own survey
		Have clearly defined criteria (marketing, technical, and financial) that must be met, as well as those that should be met, at each stage.		[25]	Various

		Go/kill criteria are defined: Having go/kill decision criteria defined for each gate, written down and visible to everyone, is a strong best practice.		[20]	APQC and PDI (Product Develop ment Institute)
Gate deliverables are defined	Gates	Gate deliverables are defined: To make good decisions, gatekeepers must have the right information available. Defined deliverables specify what information the project team must provide to enable decision making and provide a guide for gatekeepers in approaching the decision.		[20]	APQC and PDI (Product Develop ment Institute)
In the gates, decisions are actually made	Gates	Decisions are actually made: Gates are supposed ti represent decision points; the result of a gate meeting should be a go/kill decision.		[20]	APQC and PDI (Product Develop ment Institute)
		Successful businesses build though Go/Kill decision points into their new product process, where projects really do get killed. Better focus is the result.		[10]	Various
Go/no-go decisions are forecasted	Gates	Forecasting for go/no-go decisions	[Look for techniques in the book pageb366]	[26]	Various
Decisions are objective and fact based	Gates	Decisions are objective and fact based.		[20]	APQC and PDI (Product Develop ment Institute)

Monitoring should increase as projects move closer to commercialisation	Gates	Monitoring should increase as projects move closer to commercialisation due to rapidly costs over the NPD process.		[25]	Various
Hold gate meetings in virtual space	Gates	Hold gate meetings in virtual space, rather than physical space, using asynchronous (i.e., on-way) communication methods.		[25]	Various
Gatekeepers constitute an assigned cross-functional team	Gates	The PAC (Project Approval Committee) or “gatekeepers” constitute a cross-functional team that includes members from such areas such as Marketing, Finance, Research & Development, and Manufacturing. Rather than only one person (such as the CEO) The PAC (Project Approval Committee) or “gatekeepers” should consist of a different set of individuals than those actually conducting the NPD activities. Separate the initial continuation/termination decision from subsequent ones by using different teams or rotating team membership.		[25]	Various
		Designated gatekeepers are assigned: Defining the locus of decision making – the management team that makes the vital go/kill decisions at gates – is an important feature of many firm’s idea-to-launch processes.		[20]	APQC and PDI (Product Development Institute)

Gatekeepers attend to meetings, contribute to decision-making process and support decisions	Gates	Gatekeepers schedule and attend to meetings. Gatekeepers contribute to decision-making process. Gatekeepers support decisions: Gatekeeper unanimity and support for gate decisions is a problem for more than half the businesses.		[20]	APQC and PDI (Product Develop ment Institute)
Solid up-front homework	Fuzzy Front End	Vs. Not enough up-front homework: Inadequate market analysis, poor quality execution, and moving too quickly – all converge on the homework phase or fuzzy front-end of the innovation process. Vs. Not enough up-front homework: Inadequate market analysis, poor quality execution, and moving too quickly – all converge on the homework phase or fuzzy front-end of the innovation process. More predevelopment work: The homework – must be done before the product development gets under way		[10]	Various
		Solid up-front homework – doing the front-end activities well		[14]	Project NewProd
		Activities in the process include: product-line planning, strategy development, concept development, concept generation, concept screening		[15]	PDMA (1998) Benchma rking study
Ideas are actively generated by formally planned activities	Idea Generation	Ideas are actively generated by formally planned activities		[2]	PDMA 2003
		Formally planned activity to fill identified gaps in the product portfolio		[3]	PDMA 2003
		Idea generation Techniques	Emptying the box or Thinking outside the box	[4]	Various
			Brainstorming		
			Mind-mapping		
			Using your knowledge of		

			the costumer		
			Bring the experts		
		Tools	Ideation and Concept Creation , also called Brainstorming	[27]	Various
		Tools and techniques	Voice of Customer Research : Helps identify customer’s problems, unmet needs and even unarticulated needs. There is no standard methodology here, but the research usually involves working closely with customers, listening to their problems, and understanding their business or operation workflow. One technique is reverse brainstorming, i.e. identifying all that’s wrong with the current solution or product.	[28]	Various
			Camping Out with Your Customers : To uncover unmet needs and new product opportunities. Called “camping out,” “fly on the wall” or “day-in-the-life-of” research (the formal term is ethno-graphic research), it involves spending time with your customers – observing them use and abuse your products, walking in their shoes, and experiencing their frustrations – in short, almost living with them.		
			Working With Lead Customers : If you identify		

			and work closely with a select group of innovative or lead users, then you can expect much more innovative new products.		
			The Value of Scenarios: Develop alternative scenarios of future. By all means, develop the scenarios of the "official" or expected future. But develop an alternative scenario too.		
			Harnessing the Entire Organisation's Creativity: An annual off-site company conference of senior and middle people is the venue.		
Incremental approach to product development	Idea Generation	Incremental approach to product development. More productive Fundamental Research: If your company still does fundamental research, be sure to engage this unit in the Discovery stage of your new product process. Fundamental research often plants the seeds for a great new product, product family or platform.		[28]	Various
Proper Initial Idea Screening is performed	Gate 1	Predevelopment Work – the Homework: Initial screening - the decision to get into the project (the idea screen)		[16]	PDMA 2003
Proper Scoping is performed - Activities	Scoping	Scoping activities: Predevelopment Work – the Homework	Preliminary market assessment	[16]	PDMA 2003
			Preliminary technical assessment		
			Preliminary business assessment		
		Scoping activities: Sharp, Early, and Stable Project and Product Definition	Definition of the projects scope (e.g., domestic	[16]	PDMA 2003

			versus international; new product item versus platform development, etc)		
			Specification of the target market: exactly who the intended users are		
			Description of the product concept and the benefits to be delivered to the user (include value proposition)		
			Delineation of the positioning strategy, including target price		
			A list of the product's features attributes, requirements and specifications (prioritized: "must have" and "would like to have")		
		Sharp, early, fact-based product definition before development begins		[14]	Project NewProd
		Sharp and early product and project definition is one of the key differences between winning and losing at new products		[10]	Various
		Scoping activities: Concept Brief	Opportunity definition and Value proposition	[4]	Various
			Opportunity assessment		
			Market Overview		
			Strategic fit		
			Concept meets customer needs		
			Technology available for the concept		
			Financial outlay and return stimation		
Proper Business Case is	Business Case	Predevelopment Work – the Homework	Detailed market analysis	[16]	PDMA 2003
			User needs and wants studies to build in VoC		

performed - Activities			Competitive benchmarking		
			Concept testing		
			Detailed technical assessment		
			Source of supply assessment		
			Detailed financial analysis		
			Detailed business analysis		
Regulation compliance	Business Case	Regulation compliance	All regulatory issues in the product's arena are identified and addressed: patent infringement issues; industry standards and approval body regulations; and environmental, health, ergonomic, and globalization issues.	[13]	Hewlett-Packard
Proper Feasibility Review is performed	Gate 2	Feasibility review - Assessment	The technology exists	[4]	Various
			The product will meet customer needs		
			There's sufficient market for the product to ensure a good return on the company's investment		
Proper Development is performed – Activities/Tools	Development	Proper Development is performed: Testing	Lab tests	[16]	PDMA 2003
			In-house tests		
			Alpha tests		
			Prototype product		
		Engineering, R&D, and design tools/Methodologies	Failure mode & effect analysis (FMEA)	[2]	PDMA 2003
			Simultaneous/Concurrent engineering		
			Design for manufacturing, assembly, testing DFX		
			Value analysis/value engineering (VA/VE)		
			Quality function deployment (QFD)		
			Six Sigma analysis		

		Design Engineering tools are used	Design for manufacturability (DFM)	[3]	PDMA 2003
			Concurrent engineering (CE)		
			Failure mode and effect analysis (FMEA)		
			Value Analysis		
			QFD		
			Six Sigma Analysis		
			Computer aided design (CAD)		
			Computer aided engineering (CAE)		
			Project management system		
			Document management system		
			Rapid prototype system		
			Product data management system		
			Performance Modeling & Simulation		
			Resource Management Systems		
			Design for X		
		Concurrent Engineering factors	"Soft" Concurrent Engineering factors (process): Project management	[24]	Various
			"Soft" Concurrent Engineering factors (process): Formal NPD procedures		
			"Soft" Concurrent Engineering factors (process):		
			Customer/Supplier integration		
			"Soft" Concurrent		

			Engineering factors (process): Formal team briefings, Organisational redesign		
			"Hard" Concurrent Engineering factors (Tools & Techniques): Computer/networks,		
			"Hard" Concurrent Engineering factors (Tools & Techniques): Computer Aided Design (CAD)		
			"Hard" Concurrent Engineering factors (Tools & Techniques): Computer Aided Engineering		
			"Hard" Concurrent Engineering factors (Tools & Techniques): Simulation		
			"Hard" Concurrent Engineering factors (Formal Methods): Quality Functional Deployment		
			"Hard" Concurrent Engineering factors (Formal Methods): Design of Experiments		
			"Hard" Concurrent Engineering factors (Formal Methods): Design for Manufacture		
			"Hard" Concurrent Engineering factors (Formal Methods): Failure Mode Effect Analysis		
		Defining the product	Customer needs	[4]	Various
			The product may have to come in a particular price point order to fill out a product line.		

			The product may have to hit a seasonal market or meet other “window of opportunity” timing (for example, launching ahead of a competitor product).		
			The product may have to include technology that works for an entire platform of products.		
			The product may need to meet regulatory requirements.		
			The product (and processes) may have to meet environmental requirements (such as specified percent of recycled material or certain chemicals being eliminated from the manufacturing process).		
			Matrix of Product Requirements		
		Designing the product	Drafting		
			Modelling		
			Prototyping		
			Design for x		
		Developing the product	Working prototype for demonstration		
			Plan for Design for Manufacturability, signed off by manufacturing team member(s), including a description of confidence in manufacturing capabilities.		
			Determination of the key suppliers		
			Plan for manufacturing		

			scale-up		
			Completion and analysis of Alpha Testing		
			Determination of quarterly goals for performance and reliability		
			Marketing and sales commitment to ±30% volume estimate		
			Comprehensive customer service plans		
			Documentation of learnings from the Development Stage		
			Action plan and request for resources needed to proceed through the Launch Stage		
			Checklist for development review		
		Testing the product	Alpha test		
			Beta test		
		Tools	Quality function deployment	[9]	Various
			Product use testing		
			Beta testing		
			Extended use testing		
			Discrete choice modeling		
			Source of volume analysis		
			Simulated test market		
			Trial sales		
			Test market		
		Priority decision criteria list	Priority decision criteria are defined before development begins in order to make sound trade-off decisions during development.	[13]	Hewlett-Packard
		Engineering design tools	Value analysis for	[15]	PDMA

			determining the relative cost/benefit ratio for differing features sets.		(1998) Benchmarking study
			Rapid prototyping.		
			Concurrent Engineering		
		Strong voice of the customer input through all the process		[17]	PDMA's Outstanding Corporate Innovator Award
		Tools and formal methods	CAD,	[24]	Various
			Documented processes		
			Interoperability of software tools		
			Shared data		
Proper Testing and Validation are performed – Activities/Tools	Testing and Validation	Vs. Minimal testing (concept, product, market) performed (TABLE)		[1]	Own survey
		Proper Testing and Validation are performed	Product trial or limited tests	[16]	PDMA 2003
			Product beta tests		
			Product field trials		
			Production process trial or limited production runs		
			Customer acceptance test market or trial sell		
		Testing the product	Alpha test	[4]	Various
			Beta test		
		Testing	Quality function deployment	[9]	Various
			Product use testing		
			Beta testing		
			Extended use testing		
			Discrete choice modeling		
			Source of volume analysis		
			Simulated test market		
			Trial sales		
			Test market		

Proper Launch is performed - Activities	Launch	Planning and Resourcing the Launch	Post-launch plan	[16]	PDMA 2003
			Life-cycle plan		
			Post Launch Review		

Table B-5. Best Project Climate NPD practice indicators extracted from the literature review

Best Practice	Quotations	Reference	Source
Each project has a core team	Each project has a core team (TABLE). Vs. No identifiable NPD group (TABLE)	[1]	Own survey
	A clearly assigned team of players for each significant project – people who are part of the project and do work for it	[16]	PDMA 2003
Each project has a cross-functional team	Each project has a cross-functional team (TABLE)	[1]	Own survey
	Cross-functional project teams, with team members from Technical, Sales, Marketing, Operations, and so on	[16]	PDMA 2003
	Cross-functional teams –self-managing project groups with representation from the relevant department of a company.	[24]	Various
	All critical organisation functions should take part in the NPD	[9]	
	True cross-functional teams	[14]	Project NewProd
	The use of high-quality cross-functional project teams: The project has an assigned team of players – players are clearly identified. These assigned players are a cross-functional team – from R&D , marketing operation or manufacturing, engineering, and so on. The project has a defined and accountable team leader – a person who is ultimately responsible for the project. The project leader and team are responsible for the project from beginning to end (as opposed to being responsible for only one phase of a project or having project leadership change many times during a project's life). The team leader is dedicated to this one project (as opposed to leader in many projects or having many other assignments). The team interacts and communicates well and often, with frequent project update meetings, progress reviews, and problem resolution sessions. The best teams have short weekly meetings to ensure that the entire team was up to speed.	[18]	Cooper-Kleinschmidt Benchmarking studies
	Cross-functional teams are essential, but there is no magic organisational design	[19]	PDMA (1998) Benchma

			rking study
	A strong commitment to cross-functional teams as the fundamental organisation construct for executing new product development	[17]	PDMA's Outstanding Corporate Innovator Award
Cross-functional team training	Cross-functional team training	[2]	PDMA 2003
	Team-building	[3]	PDMA 2003
	Team-building	[22]	Various
Team members fit their expertise in to the project	Team members fit their expertise in to the project	[2]	PDMA 2003
	Team members fit their expertise in to the project	[3]	PDMA 2003
Cross-functional cooperation within the team	Cross-functional cooperation within the team (e.g. not too much time and effort wastes on politics, conflicts, interdepartmental prejudices, etc.).	[16]	PDMA 2003
	Team members understand the concerns of other functions	[2]	PDMA 2003
	Team members understand the concerns of other functions	[3]	PDMA 2003
	Capacity for conflict resolution and resource-sharing	[22]	Various
	The create, make, and sell functions are well interfaced and coordinated	[12]	Stanford Innovation Project
	Interaction between people from different functional groups	[10]	Early investigations
Each project has a team which remains on the project from beginning to	Each project has a team which remains on the project from beginning to end (TABLE)	[1]	Own survey
	The project team remaining on the project from beginning to end – not just on the project for a short-while or a single phase	[16]	PDMA 2003
	The team holds itself mutually accountable for work of the whole team. The team, not the individual, succeeds or fails.	[4]	Various
	Attitudes and values: Risk-sharing, mutual trust, and support. Shared goals,	[22]	Various

end	values, and project ownership.		
	True cross-functional teams: accountable	[14]	Project NewProd
Clear goals and objectives are established for teams	Clear goals and objectives are established for teams	[2]	PDMA 2003
	Clear goals and objectives are established for teams	[3]	PDMA 2003
	The team has shared goals and objectives	[4]	Various
	Clear sense of purpose and direction	[22]	Various
Team members have clear roles and work assignments	Team members have clear roles and work assignments	[4]	Various
	Self-control, accountability, and ownership. Team leadership: Clear management goals, direction, and support	[22]	Various
Cross-team exchange of lessons learned occurs	Cross-team exchange of lessons learned occurs	[2]	PDMA 2003
	Cross-team exchange of lessons learned occurs	[3]	PDMA 2003
	Continuous improvement of work process, efficiency, quality	[22]	Various
Each project has a clearly identifiable project leader	Each project has a clearly identifiable project leader (TABLE). Vs. No project leader(s) (TABLE)	[1]	Own survey
	Project leader formally appointed by management	[3]	PDMA 2003
	The team has effective leadership	[4]	Various
	Clearly identified team leader. A project leader responsible for the project from idea through to launch.	[16]	PDMA 2003
	There is a decide preference among managers in the study for structure that provide strong leadership, bolstered by formal designations of authority	[29]	
	Project Management Tools: The project manager must have authority to take action. Project management provides effective tools for estimating and planning project schedules. Employ project management software. Establish a baseline schedule and do not alter it.	[23]	Various
Dedicated leader	True cross-functional teams: dedicated leader	[14]	Project NewProd
Projects are led by a champion or process	Process ownership. Three main ownership roles: Process champion, Process Sponsor, Process Manager	[30]	PDMA 1997
	Projects are led by a champion or process owner	[3]	PDMA 2003

owner	There is a Stage-Gate process manager who guides and oversees the gating system. This person's job ensure that the process works, coach teams, facilitate gate meetings, maintain the project database, provide for training, and maintain the system and its documentation and IT support.	[20]	APQC and PDI (Product Development Institute)
	Vs. There is no NPD process owner or NPD process champion (TABLE)	[1]	Own survey
Project management leadership training	Project management leadership training. Project leadership training occurs	[2] [3]	PDMA 2003
Internal team leadership based on situational expertise, trust, and need	The influence of the team head –specifically, the extent to which the project leader is a "heavy weight" manager.	[24]	Various
	Team leadership evolves based on expertise, trust, respect. Internal team leadership based on situational expertise, trust, and need.	[22]	Various
PD activities between functional areas are coordinated through formal and informal communication	NPD activities between functional areas are coordinated through formal and informal communication (TABLE)	[1]	Own survey
	A central shared-information system for project team members	[16]	PDMA 2003
	Broad information-sharing. Effective cross-functional channels, linkages.	[22]	Various
NPD personnel are not involved in too many projects	Vs. NPD personnel are involved in too many projects (TABLE)	[1]	Own survey
Quick start-up team occurs	Quick start-up team occurs	[2]	PDMA 2003
	Quick start-up team occurs	[3]	PDMA 2003
Broad tasks	Broad tasks overlap specialized work roles.	[24]	Various

overlap specialized work roles			
Team participates in project definition	Team participates in project definition, work plans evolve dynamically. High commitment to established project goals.	[22]	Various
Team structure and responsibilities are tailored to the project and evolve and change as needed	Team structure and responsibilities evolve and change as needed. Flexibility and willingness to change.	[22]	Various
	Management styles: Successful companies appear not only to select a management style appropriate to immediate new product development needs but also to revise and tailor that approach to changing new product opportunities.	[21]	Booz-Allen & Hamilton Investigation
Minimal dependence on bureaucracy, procedures, politics	Minimal dependence on bureaucracy, procedures, politics	[22]	Various
Effective group decision-making and consensus	Effective group decision-making and consensus	[22]	Various
Control is stimulated visibility, recognition, accomplishments, autonomy	Control is stimulated visibility, recognition, accomplishments, autonomy	[22]	Various
Minimal hierarchy in member status position	Minimal hierarchy in member status position	[22]	Various
Team	Team leadership: Inspires and encourages	[22]	Various

leadership: Inspires and encourages			
Members are committed to establish objectives and plans	Members are committed to establish objectives and plans	[22]	Various
High involvement, energy, work interest, need for achievement, pride, self-motivated	High involvement, energy, work interest, need for achievement, pride, self-motivated.	[22]	Various
High morale and team spirit	High morale and team spirit	[22]	Various
Self-development	Self-development	[22]	Various
An innovative climate and culture	Innovative behavior	[22]	Various
	An innovative climate and culture: There is a new product idea scheme within the firm that solicits ideas from all the employees. Technical people are given free time, scouting time, or time off to work on projects of their own choice. Resources are made available to employees so that they can informally pursue their own projects or undertake creative work on their own choice. Such resources often include seed money for technical research and bootstrapping accounts to fund unapproved projects. Skunk works or teams working on unofficial projects are encouraged.	[18]	Cooper-Kleinschmidt Benchmarking studies
Ability to stretch beyond agreed-on objectives	Attitudes and values: Ability to stretch beyond agreed-on objectives	[22]	Various

B.3 *Best practice indicators* gathering and ranking

The NPD practice indicators are written down and rated based on the number of times that they are quoted in the reviewed literature. The statements rated with 5 or a superior value are considered best practice indicators for the purpose of this study (Table B-6: dark orange cells):

- "Performing a good marketplace research"
- "Obtaining customer/user needs"
- "Having a clear well defined NPD process exists (formal process is in place)"
- "Using tools and techniques for defining, designing, developing, and testing the product are applied"
- "Having a cross-functional team"
- "Having a clearly identifiable project leader"

Two more quotations were selected in order to allow industry comparison and validation (Table B-6: light orange cells):

- "Were technology tools applied in order to aid the development process?"
- "Were technology tools applied in order to aid the development process?"

The numbers in Table B-6 allude to the references displayed in Table B-2.

Table B-6. Best practice indicators gathering and ranking

Total rating: Average=2.26, Standard Deviation=2.15, Median=2, Mode=1.

TOTAL	Dimension	TOTAL	Subcategory	TOTAL	PDMA 2003 [2] [3] [16]	Various [8]	Own survey [1]	PDMA's Outstanding Corporate Innovator Award [17]	Magazine [5]	Booz-Allen & Hamilton Investigation [21]	Various [7]	Project NewProd [11] [14]	Early Investigations [10]	Various [10]	APQC and PDI (Product Development Institute) [20]	Various [20]	Cooper-Kleinschmidt Benchmarking studies [18]	PDMA 1998 [15] [19] [31]	Various [6]	Various [4]	Various [26]	Various [29]	Various [27]	Various [24]	Various [28]	Various [25]	Various [23]	Journal paper [31]	Various [22]
32	Research	4	Concept testing is consistently undertaken and expected with all NPD projects	1			1																						
			Product testing is consistently undertaken and expected with all NPD projects	1			1																						
			Market testing is consistently undertaken and expected with all NPD projects	1			1																						
			Results of testing (concept, product, market) are formally evaluated	1			1																						
		22	*Marketplace research (market size, segmentation, competition, etc.)	8	1		1		1			1	1	1						1									
			*Customer/user needs obtained	14	1	1	1		1		1	1	1	1				1	1	1					1				
		4	Technological leverage	2								1																	
			Marketing leverage	2								1																	

		1	The R&D process is well planned and executed	1																									
		1	Successes have a quality R&D effort, based on strong interfaces with manufacturing	1																									
72	Process	20	%A clear well defined NPD process exists (Formal process is in place)	7	1		1	1					1		1		1	1											
			%The NPD process is visible and documented	3			1								1														1
			%The NPD process is executed with discipline (Process is really used)	3			1							1	1														
			%The NPD processes enable project teams to access resources they need to succeed (Process facilitates success)	1											1														
			%The NPD process is executed with discipline quality* (Process incorporates checks)	2	1									1															
			%The NPD process is flexible and adaptable to meet the needs, size, and risk of individual projects (Process is adaptable & scalable)	4			1	1							1											1			
		2	A common NPD process cuts across company groups	2			1							1															
		2	The company follow a multistep NPD process	2						1				1															
		1	Continuous improvement of the process	1											1														

		1	*Technology tools aid the NPD process*	1	1																								
		1	An IT infrastructure with appropriate hardware, software, and technical support is available to all NPD personnel	1			1																						
		1	*The collaboration between NPD (external) partners is enhanced*	1	1																								
		8	Go/No-Go criteria are clear and pre-defined for each review gate	3			1								1										1				
			Gate deliverables are defined	1											1														
			Hold gate meetings in virtual space	1																					1				
			In the gates, decisions are actually made	2										1	1														
			Decisions are objective and fact based	1											1														
		1	Go/no-go decisions are forecasted	1																	1								
		1	Monitoring should increase as projects move closer to commercialisation	1																					1				
		2	Gatekeepers constitute an assigned cross-functional team	2											1										1				

		2	Gatekeepers attend to meetings, contribute to decision-making process and support decisions	2										1											1				
		3	Solid up- front homework	3								1	1					1											
		4	Ideas are actively generated by formally planned activities*	4	1											1				1			1						
		1	Incremental approach to product development	1												1													
		1	Proper Initial Idea Screening is performed	1	1																								
		4	The Scoping activities are performed and the documentation is elaborated*	4	1							1		1						1									
		1	The Business Case analysis is performed and the documentation is elaborated*	1	1																								

		1	Regulation compliance is ensured	1																									
		1	Proper Feasibility Review is performed*	1																1									
		7	*Tools and techniques for defining, designing, developing, and testing the product are applied*	7	1			1										1		1				1	1				
		2	Fast development*	2	1																					1			
		4	Proper Testing and Validation is performed*	4	1		1													1					1				
		1	Proper Launch is performed*	1	1																								
61	Project Climate	17	Each project has a core team	2	1		1																						
			Each project has a cross-functional team	8	1		1	1				1					1	1						1				1	
			Cross-functional cooperation within the team	4	1								1																1
			Each project has a team which remains on the project from beginning to end	2	1		1																						
			NPD personnel are not involved in too many projects	1			1																						

		2	Cross-functional team training	2	1																								1
		2	Clear goals and objectives are established for teams	2	1																								1
		1	Team participates in project definition	1																									1
		2	Team structure and responsibilities are tailored to the project and evolve and change as needed	2						1																			1
		4	The team holds itself mutually accountable for work of the whole team	4	1												1			1									1
		2	Cross-team exchange of lessons learned occurs	2	1																								1
		1	Team members fit their expertise into the project	1								1																	

		2	Team members have clear roles and work assignments	2																1									1
		1	Quick start-up team occurs	1	1																								
		8	Each project has a clearly identifiable project leader	5	1		1													1		1					1		
			Dedicated leader	1								1																	
			Internal team leadership based on situational expertise, trust, and need	2																				1					1
		1	Project management leadership training	1	1																								
		4	Projects are led by a champion or process owner	4	1		1								1			1											
		3	PD activities between functional areas are coordinated through formal and informal communication	3	1		1																						1
		1	Broad tasks overlap specialized work roles	1																				1					

		1	Minimal dependence on bureaucracy, procedures, politics	1																									1
		1	Effective group decision-making and consensus	1																									1
		1	Control is stimulated visibility, recognition, accomplishments, autonomy	1																									1
		1	Minimal hierarchy in member status position	1																									1
		1	Members are committed to establish objectives and plans	1																									1
		1	High involvement, energy, work interest, need for achievement, pride, self-motivated	1																									1
		1	Self-development	1																									1

		1	Ability to stretch beyond agreed-on objectives	1																									1
		2	An innovative climate and culture	2													1												1

B.4 Survey structure

The survey is structure as explained below:

- An introduction and an ending (Figure B-1: blue boxes)
- Three demographic questions (Figure B-1: purple boxes): Dependent variables.
- Eight binary questions in regard to the fulfillment of the good practice indicators (Figure B-1: yellow boxes): Independent variables.
- Eight "Why" questions (Figure B-1: green boxes). If the survey contestants answer negatively to the binary questions, they are asked to give a reason: Dependent variables.
- Four "Tool" questions (Figure B-1: orange boxes). If the survey contestants answer affirmatively, in some occasions they are asked to give more details. Comparison variables.

Therefore, the survey contestants have to answer between 15 and 19 questions.

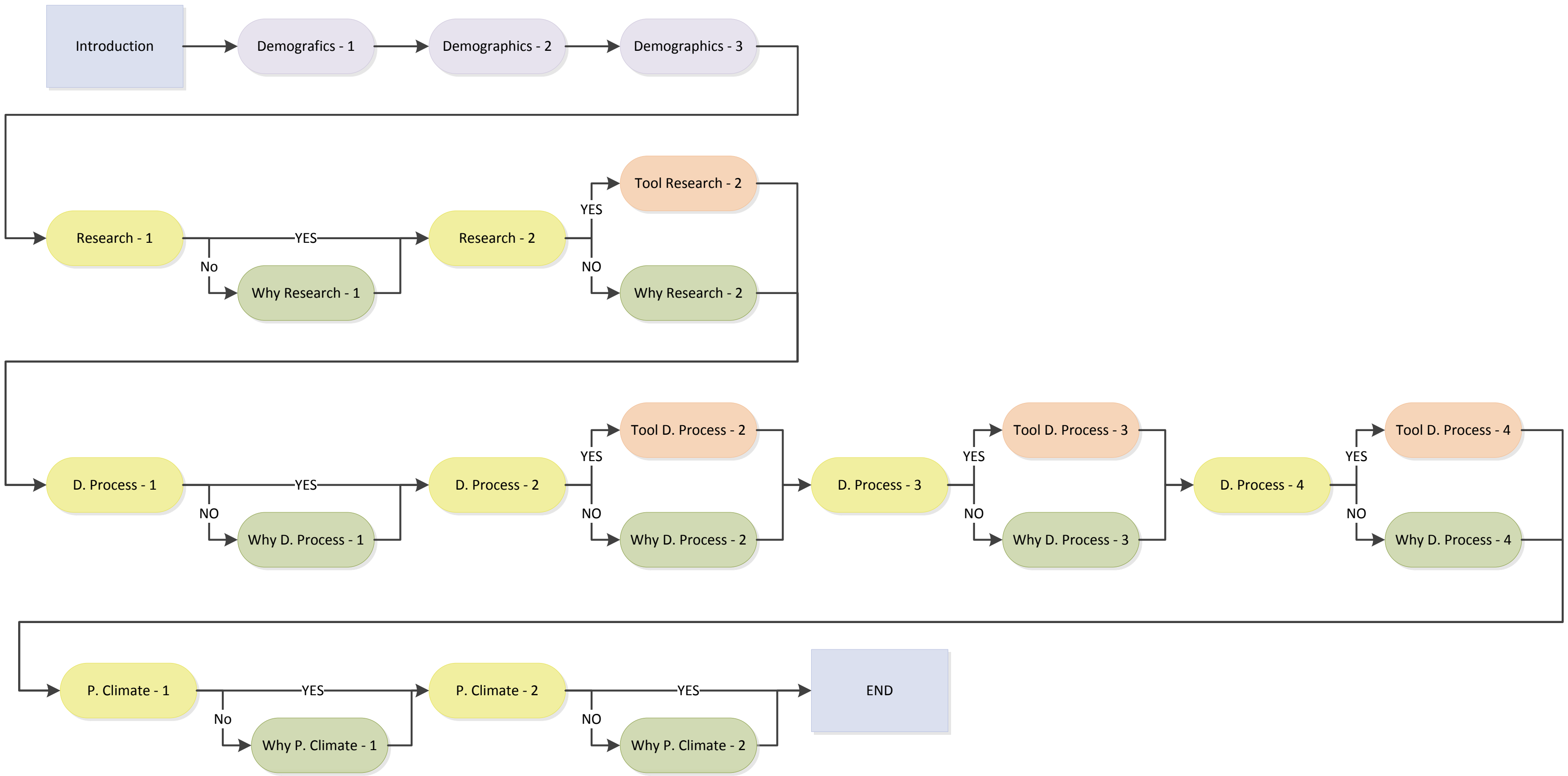


Figure B-1. Survey structure map

B.5 Survey reproduction

New Product Development at Universities

I would like to inform you that currently I am conducting a research entitled "New Product Development at Universities" for a MRes at Cranfield University.

The main objectives of the study are the following:

- To study the product/process/technology development practices at universities.

- To compare the universities performance with the industry.

In order to achieve the mentioned objectives, I would highly appreciate your collaboration by completing the survey provided. It should not take longer than 8 minutes.

The survey targets people who fulfills these three criteria:

1. They were involved in the development of a product, process, or technology that is meant to be applied on a product or process.

2. They performed the project in behalf of a university.

3. The project was in collaboration with either industry/business, government, or a NGO.

The survey respondent can fill as many questionnaires as projects under the above mentioned conditions he has been involved.

The survey is totally anonymous, none information provided would enable personal, university or company identification.

For any doubt please do not hesitate to contact me at the e-mail address.

Thank you very much for your collaboration.

Belén Iglesias Bares

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*The questionnaire asks about the performance of some common development practices. I will be the only person with access to the data. It will be kept on a server and it will be totally deleted before the 1st of June of 2014. The results will be included in the final report of my MRes and they may be published in a journal paper.

If you press the "Continue" button, you agree in taking part in the survey. Since the data is collected anonymously, data withdraw is no possible once you submit the questionnaire.

*Required

Project information

In this section we ask for information regarding to the development project.

1. **Indicate the county/province/state where the university where you developed the project is located: ***
   For example: Bedfordshire, Pontevedra, or Arizona.

   ....

2. **Indicate the industry/sector of the partner organization: ***
   The partner organization can be either industry/business, government, or a NGO.
   Mark only one oval.
   - Consumer goods
   - Healthcare products, supplies, equipment
   - Industrial, equipment, mechanical
   - Chemical, including polymers
   - Telecommunications equipment
   - Electronics/computers
   - Software
   - Other business-to-business
   - Services
   - Other

3. **Indicate the number of employees of the partner organization:** *
The partner organization can be either industry/business, government, or a NGO.
Mark only one oval.

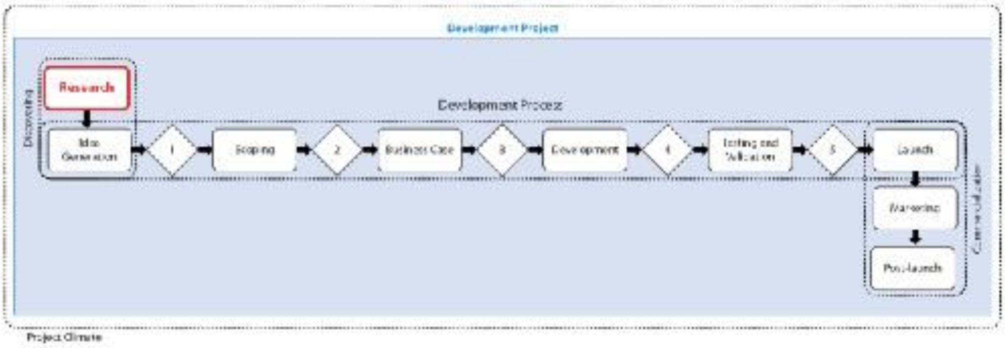
- ⬭ 1 to 10 employees (micro-entity)
- ⬭ 11 to 50 employees (small company)
- ⬭ 51 to 250 employees (medium company)
- ⬭ 250 or more employees (big company)

Development practices

You will be asked if specific development practices were applied in the course of the project. If the answer is YES, you will be inquired if some particular activities were performed. If the answer is NO, you will be asked for the reason.

The focus of this survey is on the Research, the Development Process, and the Project Climate dimensions.

Research



Research practices - 1

4. **Was marketplace research performed?** *
For instance: Analysis of the market size, market segmentation, or competitive analysis.
Mark only one oval.

- ⬭ YES *Skip to question 6.*
- ⬭ NO *Skip to question 5.*

Marketplace research was NOT performed

Skip to question 6.

5. **What was the main reason for not performing a marketplace research?** *

Mark only one oval.

- ( ) It was out of our scope
- ( ) Omission (it was not relevant for this project)
- ( ) Lack of expertise (we did not know how to perform it)
- ( ) Lack of resources (budget, facilities, personnel...)
- ( ) Lack of time
- ( ) Lack of managerial support
- ( ) I do not know

Research practices - 2

Skip to question 6.

6. **Were customer/user needs obtained?** *

Referring to the customer/user of the product, process or technology developed. These needs can be obtained for example, but not exclusively, by: Beta testing, customer site visits, voice of the customer (VoC), or alpha testing.

Mark only one oval.

- ( ) YES *Skip to question 8.*
- ( ) NO *Skip to question 7.*

Customer/user needs were NOT obtained

7. **What was the main reason for not obtaining the customer/user needs?** *

Mark only one oval.

- ( ) It was out of our scope
- ( ) Omission (it was not relevant for this project)
- ( ) Lack of expertise (we did not know how to perform it)
- ( ) Lack of resources (budget, facilities, personnel...)
- ( ) Lack of time
- ( ) Lack of managerial support
- ( ) I do not know

Customer/user needs YES obtained

Skip to question 9.

8. **What tools/techniques were applied for obtaining the customer/user needs?** *

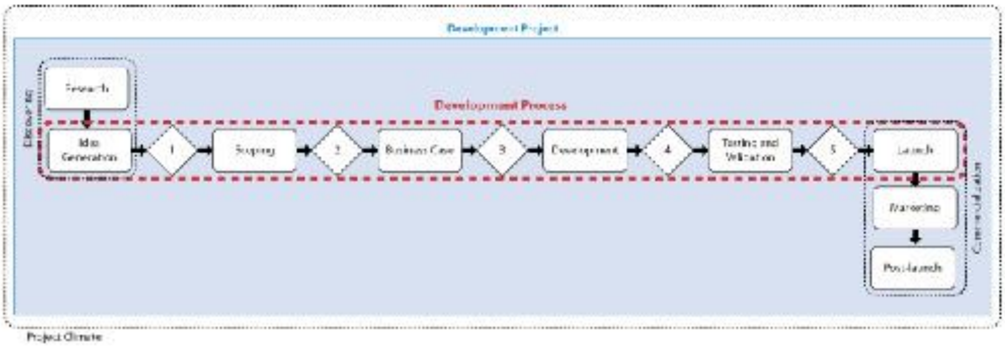
Tick all that apply.

- [ ] Beta testing (tests of working models by users)
- [ ] Customer site visits (observe and interview at their workplace)
- [ ] Voice of the customer or VoC (1-on-1 in-depth interviews for needs)
- [ ] Alpha testing (early testing with users)

- ☐ Focus groups (interview as a group for needs)
- ☐ Concept tests (customer evaluation of concept statements)
- ☐ Lead users (analysis and/or inclusion)
- ☐ Test markets
- ☐ Gamma testing (testing with the ideal product)
- ☐ Ethnography (observe customers and their environment for needs)
- ☐ Concept engineering (formal method for concept development)
- ☐ Trade-off analysis (conjoint, discrete choice modeling)
- ☐ Pretests markets (including STM, information acceleration)
- ☐ Creativity sessions (professionally moderated)
- ☐ Web-based versions of above tools
- ☐ Other
- ☐ I do not know

Development Process

Skip to question 9.



Development Process practices - 1

9. **Did a clear and well defined development process exist?** *

The development process is also referred as "game plan", "playbook", or "Stage-Gate" system that guides development projects from idea to launch.

Mark only one oval.

- ◯ YES *Skip to question 11.*
- ◯ NO *Skip to question 10.*

A well defined development process did NOT exist

Skip to question 11.

10. **What was the main reason for not existing a well defined development process? ***
Mark only one oval.

- ( ) It was out of our scope
- ( ) Omission (it was not relevant for this project)
- ( ) Lack of expertise (we did not know how to perform it)
- ( ) Lack of resources (budget, facilities, personnel...)
- ( ) Lack of time
- ( ) Lack of managerial support
- ( ) I do not know

Development Process practices - 2

Skip to question 11.

11. **Were technology tools applied in order to aid the development process? ***
For instance but not only: Project management systems, computer-aided design/engineering (CAD/CAE), document management systems, or rapid prototyping systems.
Mark only one oval.

- ( ) YES *Skip to question 13.*
- ( ) NO *Skip to question 12.*

Technology tools were NOT applied

Skip to question 14.

12. **What was the main reason for not applying technology tools to aid the development process? ***
Mark only one oval.

- ( ) It was out of our scope
- ( ) Omission (it was not relevant for this project)
- ( ) Lack of expertise (we did not know how to perform it)
- ( ) Lack of resources (budget, facilities, personnel...)
- ( ) Lack of time
- ( ) Lack of managerial support
- ( ) I do not know

Technology tools YES applied

Skip to question 14.

13. **What technology tools were applied in order to aid the development process? ***
Tick all that apply.

- [ ] Project management systems
- [ ] Computer-aided design/engineering (CAD/CAE)
- [ ] Document management systems
- [ ] Rapid prototyping systems

- ☐ Performance modeling and simulation systems
- ☐ Product data management systems
- ☐ Resource management systems
- ☐ Configuration management systems
- ☐ Knowledge management systems
- ☐ Customer needs/requirements analysis software
- ☐ Product portfolio management software
- ☐ Remote collaborative design systems
- ☐ Web-based sourcing management software
- ☐ Virtual reality/virtual design/CAVE technology
- ☐ Other
- ☐ I do not know

Development Process practices - 3

Skip to question 14.

14. **Was the collaboration with the partner organization enhanced with any formal mechanisms?** *

For example, but not exclusively: Integrated portfolio planning, interlocking concurrent development processes, IT tools (shared websites and groupware), or team building and training.

Mark only one oval.

- ◯ YES *Skip to question 16.*
- ◯ NO *Skip to question 15.*

The collaboration with the partner organization was NOT enhanced

15. **What was the main reason for not enhancing the collaboration with the partner organization with any formal mechanism?** *

Mark only one oval.

- ◯ It was out of our scope
- ◯ Omission (it was not relevant for this project)
- ◯ Lack of expertise (we did not know how to perform it)
- ◯ Lack of resources (budget, facilities, personnel...)
- ◯ Lack of time
- ◯ Lack of managerial support
- ◯ I do not know

The collaboration with the partner organization YES enhanced

Skip to question 17.

16. **What mechanisms were applied in order to enhance the collaboration with the partner**

organization? *

Tick all that apply.

- [ ] Integrated portfolio planning
- [ ] Interlocking concurrent development processes
- [ ] IT tools (shared websites and groupware)
- [ ] Team building and training
- [ ] Per review for performance appraisals
- [ ] Reward
- [ ] Performance structures
- [ ] Subcontract licensing agreements
- [ ] Technology licensing agreements
- [ ] Other
- [ ] I do not know

Development Process practices - 4

Skip to question 17.

17. **Were tools and techniques for defining, designing, developing, and testing the product/process/technology applied?** *

For instance: Concurrent/simultaneous engineering (CE), design for X (DFX), failure mode & effect analysis (FMEA), or quality function deployment (QFD).

Mark only one oval.

- ( ) YES *Skip to question 19.*
- ( ) NO *Skip to question 18.*

Tools or techniques for designing, developing and testing were NOT applied

18. **What was the main reason for not applying any tool or technique for defining, designing, developing, and testing the product/process/technology?** *

Mark only one oval.

- ( ) It was out of our scope
- ( ) Omission (it was not relevant for this project)
- ( ) Lack of expertise (we did not know how to perform it)
- ( ) Lack of resources (budget, facilities, personnel...)
- ( ) Lack of time
- ( ) Lack of managerial support
- ( ) I do not know

Tools or techniques for designing, developing and testing YES applied

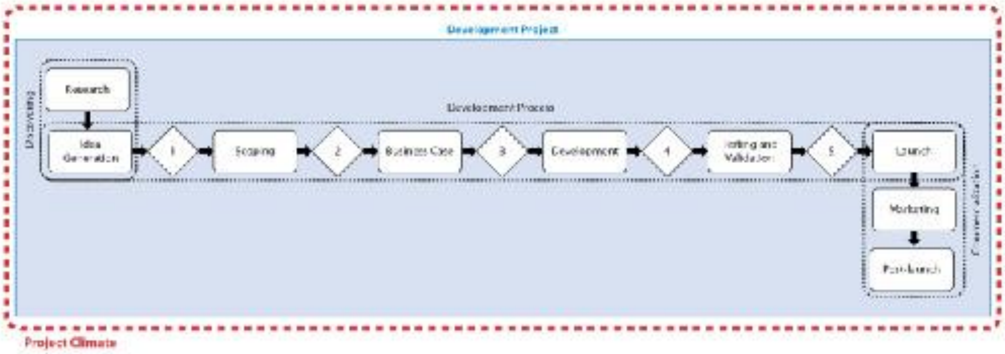
Skip to question 20.

19. **What tools or techniques for defining, designing, developing, and testing the product/process/technology were applied?** *
Tick all that apply.

- [ ] Concurrent/simultaneous engineering (CE)
- [ ] Design for manufacturing, assembly, testing: design for X (DFX)
- [ ] Failure mode & effect analysis (FMEA)
- [ ] Quality function deployment (QFD)
- [ ] Value analysis/value engineering (VA/VE)
- [ ] Six sigma analysis
- [ ] Other
- [ ] I do not know

Project Climate

Skip to question 20.



Project Climate practices - 1

20. **Was the project preformed by a cross-functional team?** *
That is, members from the Engineering, Sales, Marketing, Operations, etc. business funcions belong to the team.
Mark only one oval.

- ( ) YES *Skip to question 22.*
- ( ) NO *Skip to question 21.*

The project was NOT performed by a cross-functional team

21. **What was the main reason for not performing the project by a cross-functional team?** *
Mark only one oval.

New Product Development at Universities

- It was out of our scope
- Omission (it was not relevant for this project)
- Lack of expertise (we did not know how to perform it)
- Lack of resources (budget, facilities, personnel...)
- Lack of time
- Lack of managerial support
- I do not know

Project Climate practices - 2

Skip to question 22.

22. **Did the project have a clearly identifiable team leader?** *

Mark only one oval.

- YES *Skip to question 24.*
- NO *Skip to question 23.*

The project did NOT have identifiable team leader

23. **What was the main reason for not having a identifiable project team leader?** *

Mark only one oval.

- It was out of our scope
- Omission (it was not relevant for this project)
- Lack of expertise (we did not know how to perform it)
- Lack of resources (budget, facilities, personnel...)
- Lack of time
- Lack of managerial support
- I do not know

The End

Thank you very much for your collaboration.

Skip to question 24.

24. **If you want to receive the results of the study, please write down your e-mail address:**

25. **Do you know anybody who may be interested in this study? Write down their e-mail address, please:**

Page 10 of 11

Figure B-2. Survey reproduction

B.6 Survey distribution

The survey subjects have access to the questionnaire by one of the next means:

- Direct email (individuals related to NPD teaching, projects, or researches)
- Post in a specialized forum (targeted forum topics: related to NPD, science, technology, innovation or engineering)
- Post in a network

The details of the distribution can be found in Table B-7.

Table B-7. Survey distribution details

Entity	Mean of distribution
Cranfield University (UK)	Direct emails to potentially relevant subjects of the study or people with access to them
Universidad de Vigo (Spain)	Direct emails to potentially relevant subjects of the study or people with access to them
Universitat Politècnica de València (Spain)	Direct emails to potentially relevant subjects of the study or people with access to them
The University of Manchester: Manchester Business School (UK)	Direct emails to potentially relevant subjects of the study or people with access to them
Wisconsin School of Business: Center for Professional & Executive Development (US)	Direct emails to potentially relevant subjects of the study or people with access to them
Stanford University Online	Direct emails to potentially relevant subjects of the study or people with access to them
Birmingham City University: School of Technology, Engineering and Environment (UK)	Direct emails to potentially relevant subjects of the study or people with access to them
The University of Chicago Booth Scholl Busines (US)	Direct emails to potentially relevant subjects of the study or people with access to them
Suffolk University College of Arts and Sciences (US)	Direct emails to potentially relevant subjects of the study or people with access to them
Pennsylvania State University (US)	Direct emails to potentially relevant subjects of the study or people with access to them
University of Otago (New Zealand)	Direct emails to potentially relevant subjects of the study or people with access to them

RMTI University (Australia)	Direct emails to potentially relevant subjects of the study or people with access to them
Northwestern University: McCormick School of Engineering (US)	Direct emails to potentially relevant subjects of the study or people with access to them
Northwestern University: Segal Design Institute (US)	Direct emails to potentially relevant subjects of the study or people with access to them
Oklahoma State University: Inventor's assistance service (US)	Direct emails to potentially relevant subjects of the study or people with access to them
Carnegie Mellon University (US)	Direct emails to potentially relevant subjects of the study or people with access to them
University of Minnesota (US)	Direct emails to potentially relevant subjects of the study or people with access to them
University of Greenwich (UK)	Direct emails to potentially relevant subjects of the study or people with access to them
CEU Universidad Cardenal Herrera (Spain)	Direct emails to potentially relevant subjects of the study or people with access to them
The Students Room forum	New thread in the category: Media and research opportunities
Engineers Edge forum	New thread in the category: Design, Engineering & Manufacturing Solutions
Eng-Tips Forums forum	New thread
The Science Forum forum	New thread in the category: Business & Economics
Edulix	New thread
Physics Forum forum	New thread in the category: Engineering Systems & Design
IET (The Institute of Engineering and Technology) forum	New thread in the category: Design and production engineering
Foros de SóloIngeniería.NET fórum	New thread in the category: Calidad y organisación industrial and Miscelánea
Universia forum	New thread in the category: Tablón de anuncios
Cranfield University Intranet	New Survey
Linked In	Activity update
Facebook	State update

It is worth to stand out that more than 311 people were directly contacted by email, which means that the participation was at most 16%.

Appendix C Findings

C.1 Industry/sector of the partner organisation comparison

Comparison between the industry/sector of the partner organisations of the universities and the industry/sector of Barczak et al. firms sample (Barczak & Khan, Identifying new product development best practice, 2012).

Table C-1. Demographics – 2: Industry/sector of the partner organisation comparison.
Industry data obtained from (Barczak & Khan, Identifying new product development best practice, 2012)

Demographics – 2: Industry/sector of the partner organisation comparison	University's positive answers	Industry's positive answers
Industrial, equipment, mechanical	36.00%	21.15%
Consumer goods	18.00%	9.38%
Healthcare products, supplies, equipment	10.00%	11.54%
Electronics/computers	10.00%	11.78%
Software	6.00%	7.93%
Other	6.00%	0.96%
Telecommunications equipment	4.00%	N/A
Other business-to-business	4.00%	8.65%
Services	4.00%	9.38%
Chemical, including polymers	2.00%	19.47%

Appendix D Discussion

D.1 Case study: Eyelid Massage

The author has extensive experience on NPD projects performed at universities. The most recent and source of inspiration for this study is the development of the Eyelid Massage, an eye care product.

This project was born from the collaboration between Cranfield University and Eye Comfort Limited in an effort to bring to market a new dry eye health care product.

The Meibomian Gland Dysfunction (MGD), also called meibomitis, meibomianitis, or lid margin disease, is considered the top cause of the evaporative eye disease (Knop, et al., 2011; Trinidad Conde & Almond, 2013). It results on itchiness, burning eyes, light sensitivity and blurred vision among other symptoms. The anatomy of the meibomian glands is described in Figure D-1 and typical symptoms of the MGD are illustrated in Figure D-2.

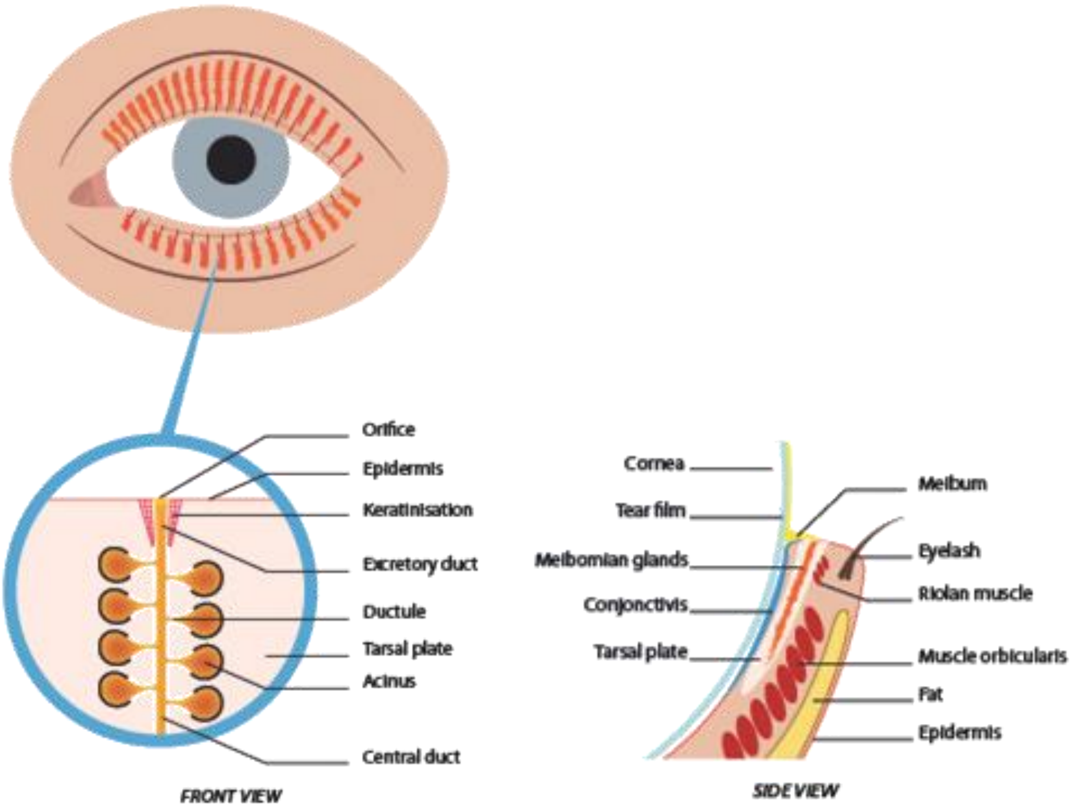


Figure D-1. Meibomian Gland anatomy

(Le Mentec & Williams, 2012)

A) B)

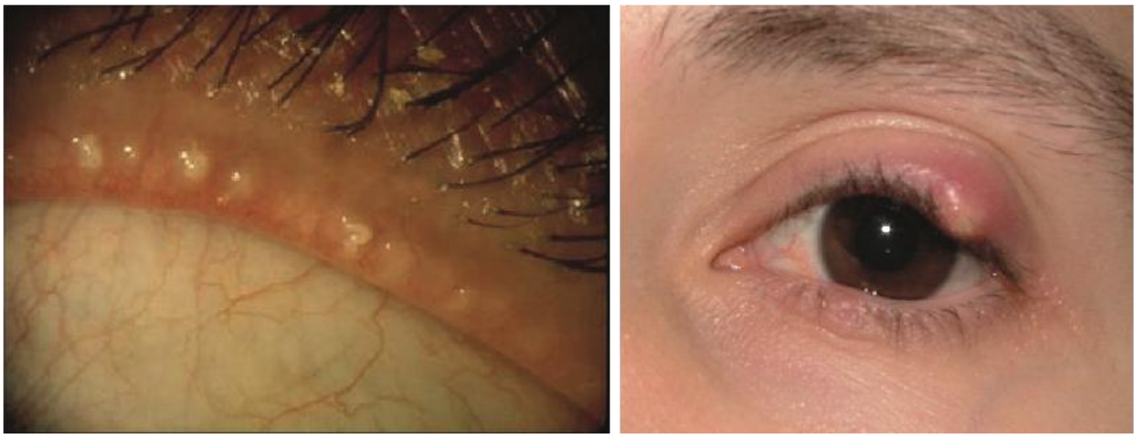


Figure D-2. Most evident Meibomian Gland Dysfunction symptoms

A) Clogged glands, B) Chalazion, also known as a meibomian gland lipogranuloma

As Le Mentec concluded in the first research, in regard to the MGD, “the therapy typically involves the process of heating the eyelids to liquefy the secretion followed by a vertical massage to express the glands” (Le Mentec & Williams, 2012). Based on these insights, and after many designs and trials, a new device for the prevention of the MGD was invented; the Eyelid Massage (Figure D-3). Note that akin to the toothbrush, that is meant to prevent cavities but not to treat them, the Eyelid Massage is not meant to treat the MGD, but to prevent it by a daily use.

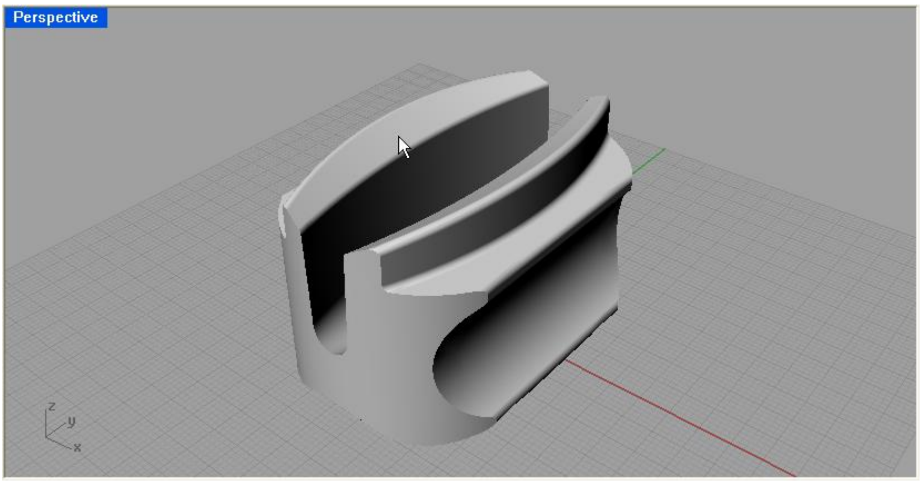


Figure D-3. Early Eyelid Massage design.

The maximum dimensions were approximately 60X41X36 mm

The device is made of one single part and material. It was designed to be heated in a microwave oven, and it intends to vertically massage the meibomian glands as displayed in Figure D-4.

Figure D-4. Diagram of use.
Instructions: "Place the Eyelid Massage on your closed eyelids as indicated and gently squeeze and release between 5-20 times daily or as required" (Modification from of Le Mentec's diagram)

Le Mentec and Trinidad Conde also made a first material selection and some early prototypes of the device (Le Mentec & Williams, 2012; Conde & Almond, 2013).

The author joined the project in February of 2013. The task was to develop and launch the Eyelid Massage.

After a deep research on the MGD dysfunction and the Eyelid Massage operation, a benchmarking study was performed and a business model was generated (Figure D-5). Following, the relevant regulations were studied. It was concluded that the main European regulation that regard the Eyelid Massage is the Medical Devices Directive (MDD 93/42/ECC) (Council of the European Communities, 2007). From this regulation and other supporting literature, a process map for CE marking process of the device was defined (Figure D-6). However, finally it was decided not to market the Eyelid Massage as a medical device. The compulsory clinical study for all the products under the medical devices regulations would have exceeded the project time frame. Besides, it was possible to market the Eyelid Massage as a healthcare product. Although this approach simplifies the development process, it also has some withdraws. The main one is that the manufacturers are not be allowed to state any of the potential positive clinical effects. As a result, clinical terms like “Meibomian Gland Dysfunction”, “blepharitis”, “dry eyes”, “treatment” or “prevention” are not legally allowed in any official document referring to the Eyelid Massage. Thus, there is the risk of not reaching the desired customer segment. Instead, the manufacturers can use terminology related to the well-being, like “massage”, “comfort” and “relax”.

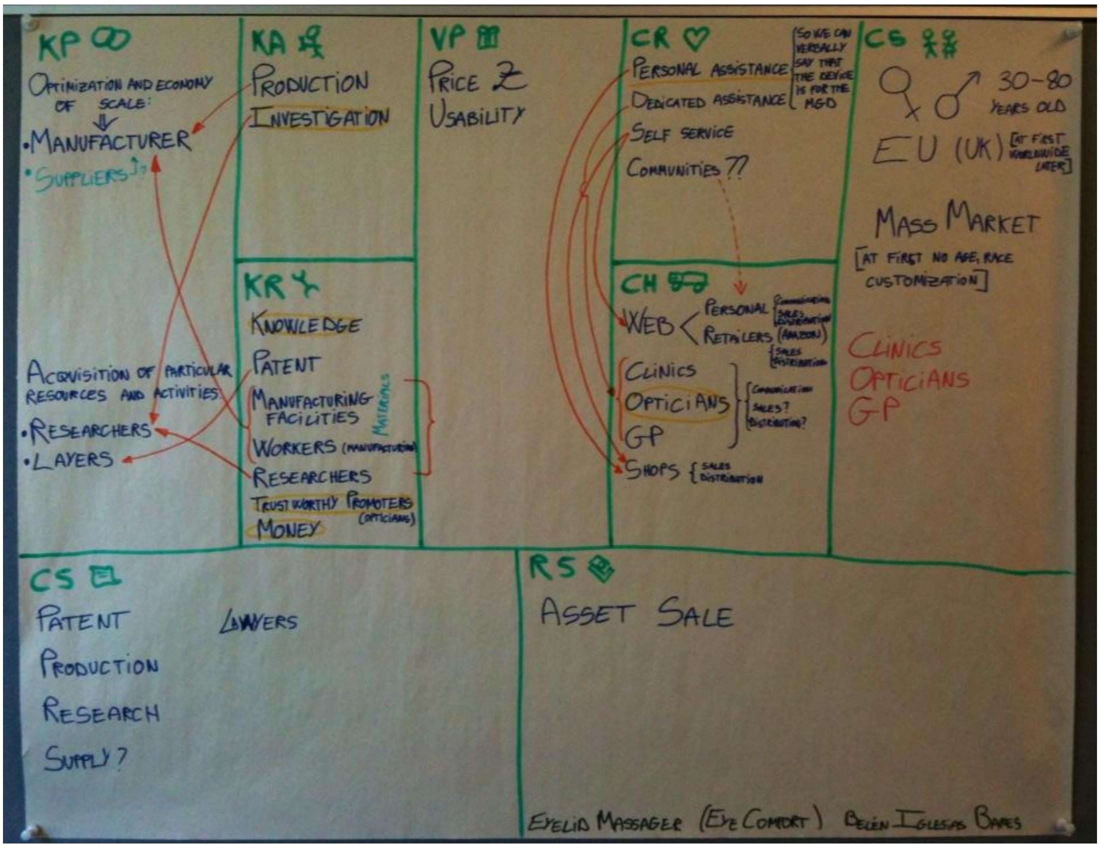
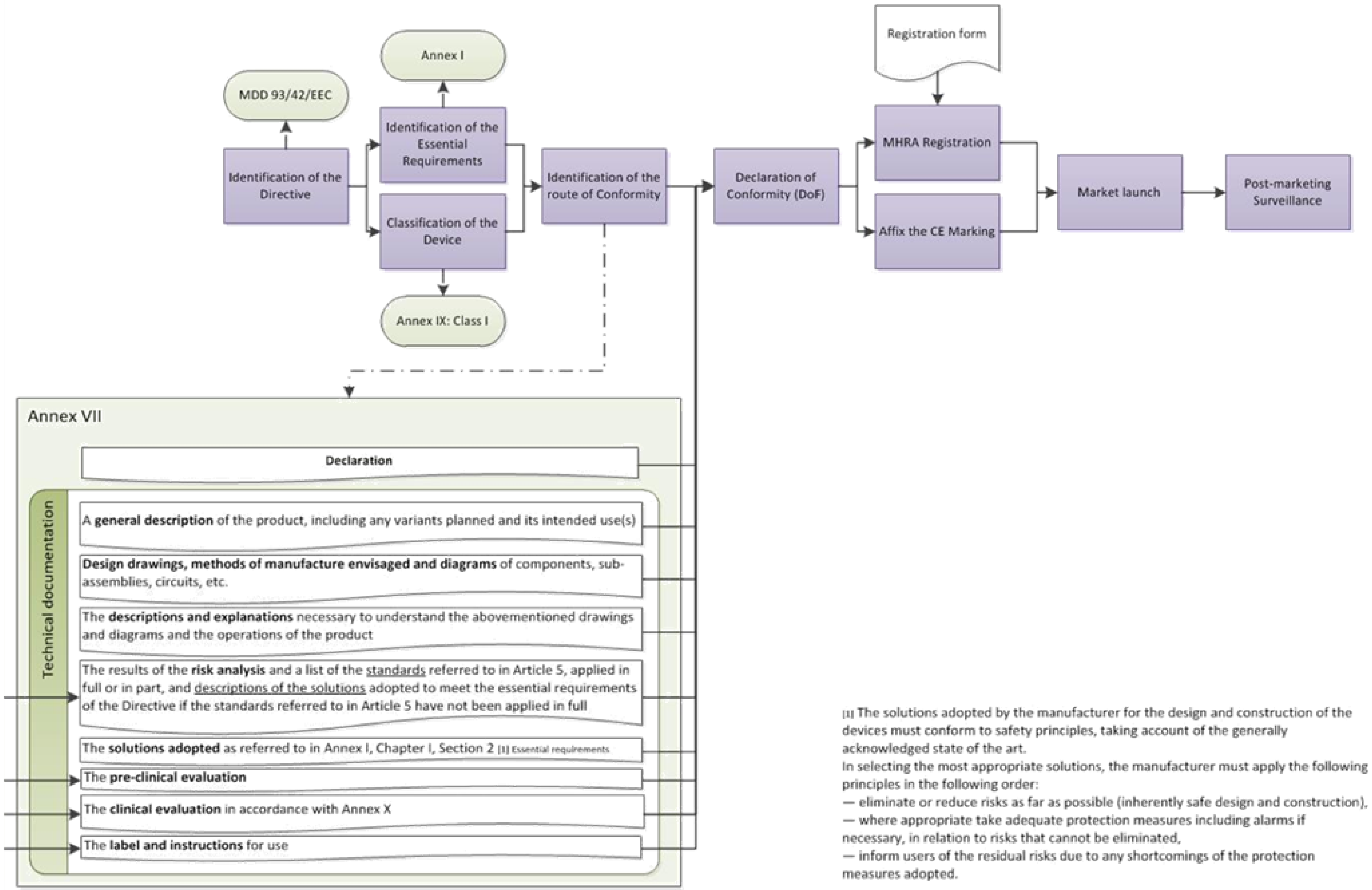


Figure D-5.Eyelid Massage business model for Eye Comfort Ltd.

Based on the “Business model generation” canvas (Osterwalder & Pigneur, 2010)


MDD 93/42/EEC
Identification of the Directive
Annex I
Identification of the Essential Requirements
Classification of the Device
Annex IX: Class I
Identification of the route of Conformity
Declaration of Conformity (DoF)
Registration form
MHRA Registration
Affix the CE Marking
Market launch
Post-marketing Surveillance
Annex VII
Declaration
Technical documentation
A **general description** of the product, including any variants planned and its intended use(s)
Design drawings, methods of manufacture envisaged and diagrams of components, sub-assemblies, circuits, etc.
The **descriptions and explanations** necessary to understand the abovementioned drawings and diagrams and the operations of the product
The results of the **risk analysis** and a list of the standards referred to in Article 5, applied in full or in part, and descriptions of the solutions adopted to meet the essential requirements of the Directive if the standards referred to in Article 5 have not been applied in full
The **solutions adopted** as referred to in Annex I, Chapter I, Section 2 [1] Essential requirements
The **pre-clinical evaluation**
The **clinical evaluation** in accordance with Annex X
The **label and instructions** for use
[1] The solutions adopted by the manufacturer for the design and construction of the devices must conform to safety principles, taking account of the generally acknowledged state of the art.
In selecting the most appropriate solutions, the manufacturer must apply the following principles in the following order:
— eliminate or reduce risks as far as possible (inherently safe design and construction),
— where appropriate take adequate protection measures including alarms if necessary, in relation to risks that cannot be eliminated,
— inform users of the residual risks due to any shortcomings of the protection measures adopted.

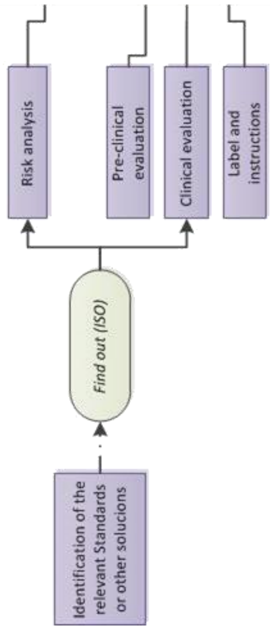


Figure D-6. CE Marking process map for the Eyelid Massage
Based on the information obtained from (Council of the European Communities, 2007)(Fries, 2001)(MHRA, 2013)(Summerhayes & Sivshankar, 2006).

Functional prototypes were built. The prototyping process starts with the CAD design of the mould (Figure D-7: 1. Mould design). Secondly the design is rapid prototyped in *vero white* material, thus it allows good accuracy and it provides smooth non-porous finishing (Figure D-7: 2. Mould rapid prototyped). In order to improve the surface finishing the mould is polished (Figure D-7: 3. Polishing the mould). Before casting the material, the mould is sprayed with a releasing agent for the purpose of preventing the part sticking to the mould (Figure D-7: 4. Applying the releasing agent). The fifth step is to prepare the material. It was decided to prototype with room temperature vulcanization rubber (RTV) 20 shore A hardness (Bentley Advanced Materials: Dragon Skin 20) in blue vein colour. The "*Dragon Skin* is often used to cast silicone parts especially in such fields as special effects appliances, skins for animatronics, orthopedic cushioning, prosthetic or fake body parts, robotics, and prototyping" (Bentley Advanced Materials, 2012). As a result, the material was appropriate for temporal skin contact. The *Dragon Skin* material is provided in two parts that have to be mixed in equal proportions. The mixing has to be exhaustive in order to avoid heterogeneities in the final part. Then, in many cases the dye with a pipette has to be added to the mixture (Figure D-7: 5. Mixing components and colouring). From the moment that the two parts are mixed, the curing process starts. The rest of the process has to be performed very quickly, otherwise the mixture will become thick and air bubbles will be trapped despite the de-airing process. The mixture is firstly de-aired in the mixing container (Figure D-7: 6. De-airing the mixture). Then, it is poured in the assembled mould (Figure D-7: 7. Pouring the mixture in the mould). Finally, it is de-aired again in the mould (Figure D-7: 8. De-airing the mould). The material solidifies totally in 4 hours (Figure D-7: 9. Curing). After demoulding the part (Figure D-7: 10. Demoulding) and removing the sprue and feeder positive, the part finally is placed in a post-curing oven for an extra hour so that the material does not stick (Figure D-7: 11. Post-curing).

Figure D-7. Prototyping process

These prototypes were used for a preliminary assessment with users and as a reference for the manufacturers. An interim packaging and labelling (including the logotype) was also designed and made for them (Figure D-8).

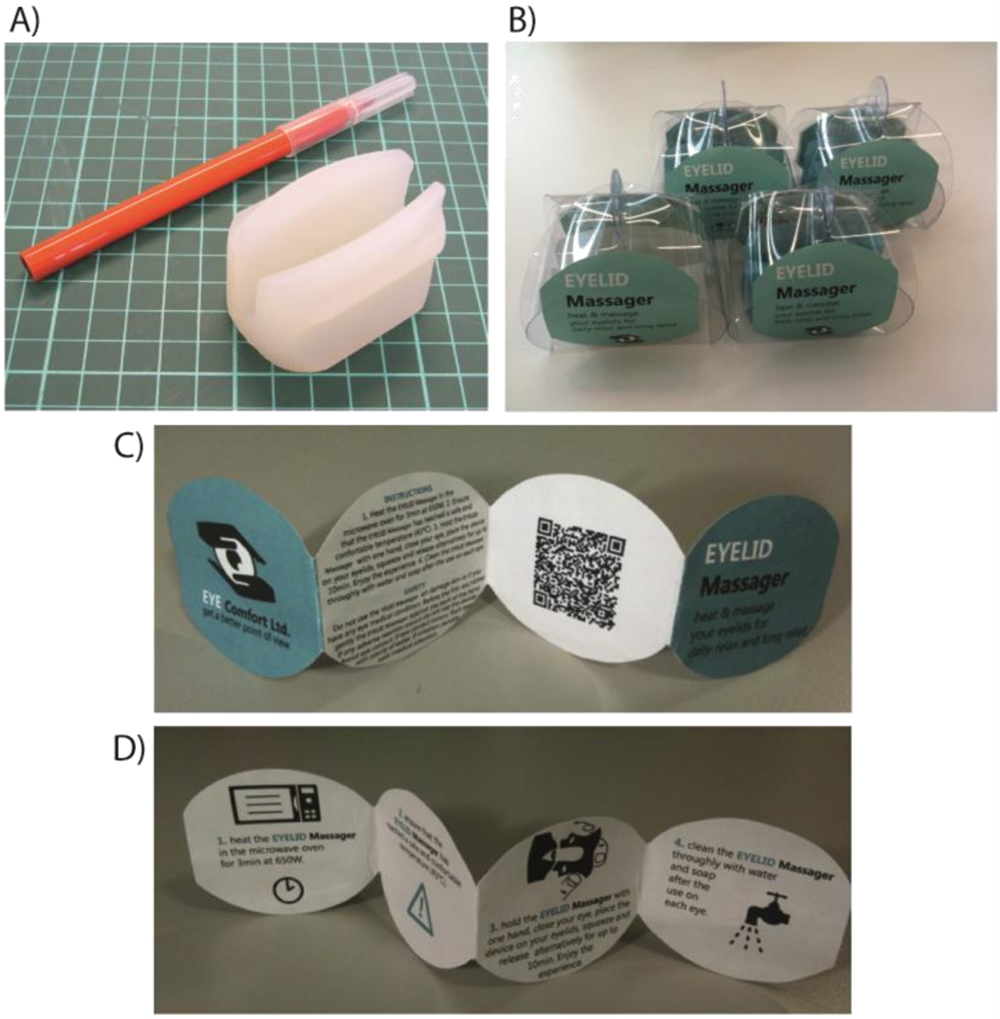


Figure D-8. Prototypes

A) Not dyed prototype, B) Prototypes in interim packaging, C) Interim labelling front, D) Interim labelling back.

The tests with the prototypes revealed that the Eyelid Massage was too big. As a result the design was reduced by 20%. The logotype created by a graphic designer was also embossed in the CAD file of the product. The first logotype was read "eyemassage", however in order to avoid misunderstandings the name of the product was changed afterwards to "eyelidmassage".

The previous researcher already set some of the material requirement (biocompatibility and 22 hardness Shore A) and suggested to use silicone rubber (Trinidad Conde & Almond, 2013). Although the meibum liquefies between 32-45°C

(Knop, Knop, Millar, Obata, & A., 2011), the heating tests performed by Trinidad report that the device, heated in a conventional microwave oven, could exceed 120°C fairly easily. For example, in one of the experiments the Eyelid Massage was placed in a microwave oven and subjected to 850W for 2 minutes. The device reached 122°C. Consequently, the maximum service temperature of the material was set to 125°C. The material density (1.88g/cc) and the material tensile strength (40MPa) references (Higgins, 1977) were the values of these properties for the silicone, although these requirements are relatively less important than the others. After an online research, it was found that the Liquid Silicone Rubber (LSR) was a very good option for the product. However, as each company usually works with their own providers and Liquid Silicone Injection (LIM) of LSR is not very widespread, the technical requirements were stated in a general fashion. The material requirements are summarised in Table D-1.

Table D-1. Eyelid Massage material requirements

Material requirements	
Biocompatibility:	Skin contact, medical grade (the device does not have to comply with any medical directive, therefore the skin sensitization test is not required, but desirable). The final part MUST be TOTALLY clean.
Density ≈	1.88 g/cc
Hardness (Shore A) ≈	22
Tensile Strength (Ultimate) ≈	40 MPa
Maximum Service Temperature (in Air) ≈	150 °C
Colour:	Transparent, translucent, translucent coloured (blue?), milky, milky coloured, white...

The search of a manufacturing company initially followed the next criteria:

- Capable of injection, compression, or transfer moulding. Preferably injection moulding, and ideally LIM of LSR.
- Capable of manufacturing by any of these means a material that fulfils the material requirements. Preferably LSR.

- Company settled in UK, or in Europe as furthest.

More than 40 manufacturing companies were contacted and asked to sign a No Disclosure Agreement (NDA). Only 18 of them had capabilities for the project and were sent the product dossier (Figure D-9). Based on the dossier information the companies sent their quotations and then the offers and capabilities were evaluated. Only 6 of the manufacturers (3 in Northern Ireland and 3 in England) were considered. Four of them were even visited to check their facilities.

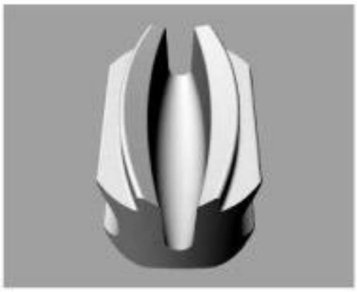
Eye Comfort Eyelid Massage

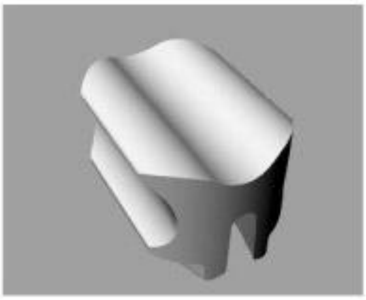
Product Dossier

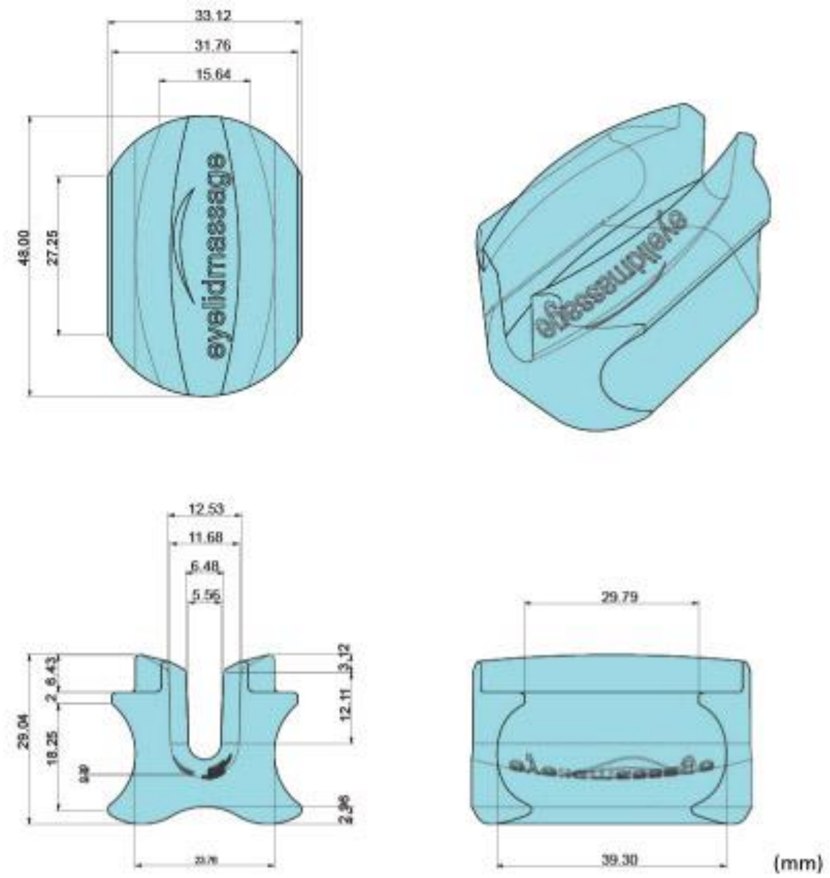
October 2013

The Eyelid Massage from Eye Comfort is intended to massage the eyelid. It is not supposed to touch the eye, however, accidental eye contact may occur. The Eyelid Massage is manually operated, i.e. there is not an external energy supply. The device is going to be heated in a microwave oven. But, the normal working environment is the atmosphere, i.e. it is not going to be in contact with any substance apart from water and maybe soap for cleaning it.

THE EYE COMFORT EYELID MASSAGER







EYE COMFORT EYELID MASSAGE PROPERTIES

Dimensions:	
Maximum Dimensions:	48 X 33.12 X 29.04 mm
Volume:	22.16 cm^3
Material properties:	
Biocompatibility:	Skin contact, medical grade (the device does not have to comply with any medical directive, therefore the skin sensitization test is not required, but desirable). The final part MUST be TOTALLY clean.
Density ≈	1.88 g/cc
Hardness (Shore A) ≈	22
Tensile Strength (Ultimate) ≈	40 MPa
Maximum Service Temperature (in Air) ≈	150 °C
Colour:	Transparent, translucent, translucent coloured (blue?), milky, milky coloured, white...

Eye Comfort Eyelid Massage

Example of the desired material: Mini massager mitt (100% Silicone)

OUR QUESTIONS

1. Can you manufacture this device in your facilities?
2. Can you do injection moulding? And liquid injection moulding (LIM)? Otherwise, what techniques do you use? Compression, transfer moulding?
3. What material do you suggest to use? Could you please provide us with the properties and price of such material? Can you work with liquid silicone rubber (LSR)?
4. Do you usually manufacture medical or food grade products? Do you have clean rooms?
5. Could you please give a quotation for the die design and manufacturing? Can you provide the approximate time frame for this?
6. Could you please give a quotation for the production of a first batch of 1000, 5000 and 10000 units? If the product is successful, we will be interested in extending the production. Can you provide the approximate time frame for this?
7. Do you provide packaging service?

3

Belén Iglesias Bares

Figure D-9. Eye Comfort Eyelid Massage Product Dossier reproduction

A simplified comparison of the companies is displayed in Table D-1.

Table D-2. Manufacturing companies' comparison

Company	Location	Experience with medical/food products	Technology	Price	Service
1	England	None	Compression moulding	Average	Low interest
2	England	None	Compression and transfer moulding	Lowest	Highest interest
3	England	None	Compression moulding	Average	Lowest interest
4	Northern Ireland	Specialist	Injection moulding	Highest	High
5	Northern Ireland	None	Injection moulding	Average	Average
6	Northern Ireland	Average	Injection moulding	Average	Average

In a multi-criteria evaluation of the companies, it was decided to place the order to the company 2, which involved the lowest economic risk. This company offered building a single cavity tool for a small batch production. We decided to go firstly for this option that was cheaper and allowed testing different surface finishing and future improvements in the part design. On the other hand, this company was producing by compression moulding, which is cheaper but also deliver lower quality. It was also manufacturing the parts in silicone rubber, instead of LSR.

The first samples from the selected company had some issues:

- The lower splitting line did not follow the lower edge of the part as agreed
- The parts had a strong chemical odor
- The parts have some flashing
- The parts were dirty and they had stains

The manufacturer was asked to solve those issues for the next production. They stated that they would fix the splitting line, the odour would disappear by applying post-curing to the pieces, they would try to tweak the tooling to reduce the flashing, and finally they ensured that after a few runs the tooling would self-clean and the parts would be totally clean.

Meanwhile the packaging, the labelling, the instruction, and the informative leaflets were specifically designed and ordered (Figure D-10).

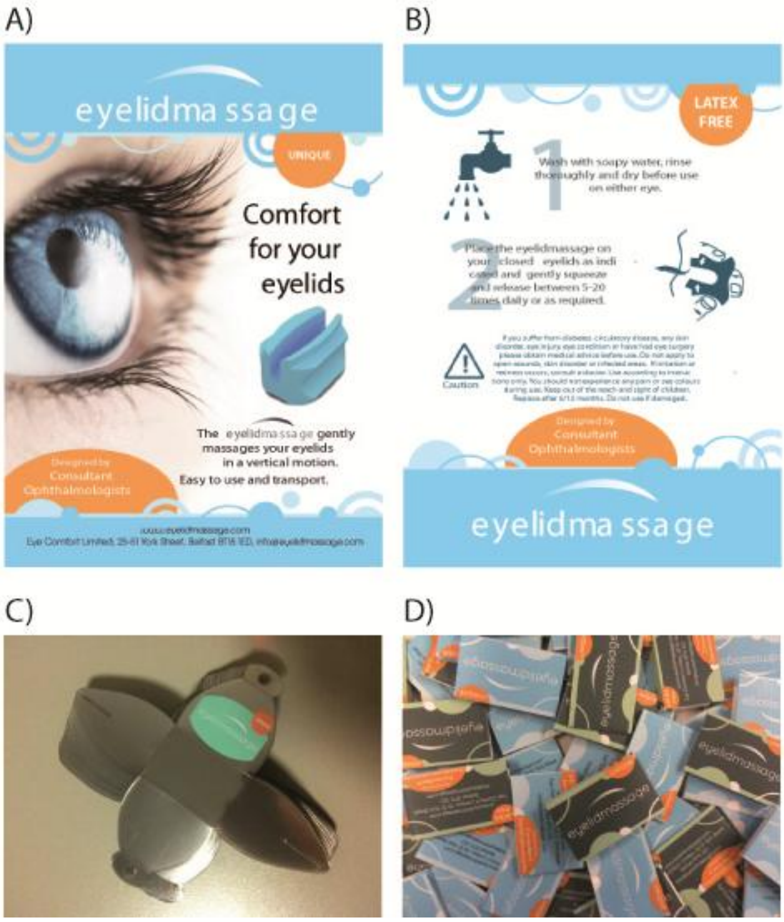


Figure D-10. A) Leaflet front, B) Leaflet back, C) Packaging, D) Instructions

Finally, 64 of the 100 ordered Eyelid Massages were received (Figure D-11).

Figure D-11. Completed set: Eyelid Massage with the instruction in the labelled

However, the manufactured Eyelid Massages still had some quality issues. Although the lower splitting line was in the right positions and the odor was fully removed, the parts still had some flashing. But the main problem was the cleanliness; almost all the parts had black stains or dirt embed in the rubber (Figure D-12).

Figure D-12. Quality issues in the Eyelid Massage: Stains, dirt, and flashing

The batch was returned to the manufactured since it did not meet the agreed requirements. The company tried again to produce the parts and to improve the quality. The next results although better, were not good enough. It was concluded that the manufacturer did not have the capability of clean production and it was decided to change provider.

In this second manufacturer search the new company requirements were:

- Capable of injection moulding. Ideally LIM of LSR.
- Capable of manufacturing by any of these means a material that fulfils the material requirements. Preferably LSR.
- Experience with medical or food products.

Note that this time the search was global and not restrict to the UK or Europe.

The process followed was the same as in the first manufacturer search: contact, signing of the NDA, and provide Eyelid Massage dossier. Around 25 businesses were contacted, 5 new quotes were received, and 3 of them were assessed in-depth. It was ensured that the same mistakes of the previous manufacturer were not going to occur again (Figure D-13).

The selected company is currently manufacturing the tooling for LIN of LSR.

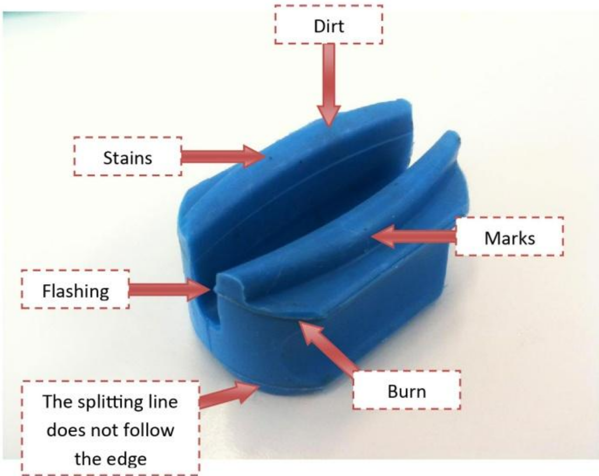
Eye Comfort Eyelid Massage

Product Requirements

November 2013

This is a summary of the requirements for the Eyelid Massage materials and manufacturing.

Material requirements:	
Biocompatibility:	Skin contact, medical grade (the device does not have to comply with any medical directive, therefore the skin sensitization test is not required, but very desirable). Material FDA and/or MHRA approved. The final part MUST be TOTALLY clean and LATEX FREE.
Hardness (Shore A) =	[22 – 25]
Maximum Service Temperature (in Air) ≥	150 °C
Colour:	Transparent, translucent, translucent coloured (blue?), milky, milky coloured, white...
Density ≈	1.88 g/cc
Tensile Strength (Ultimate) ≈	40 MPa
Manufacturing requirements (check figure below):	
No flashing	
No marks (burns, indentions, discoloration, etc.)	
No dirt	
No smell	
Splitting lines follow the edges as far as possible	



The figure shows a number of defects for which the product does not meet the requirements.

Figure D-13. Product requirements